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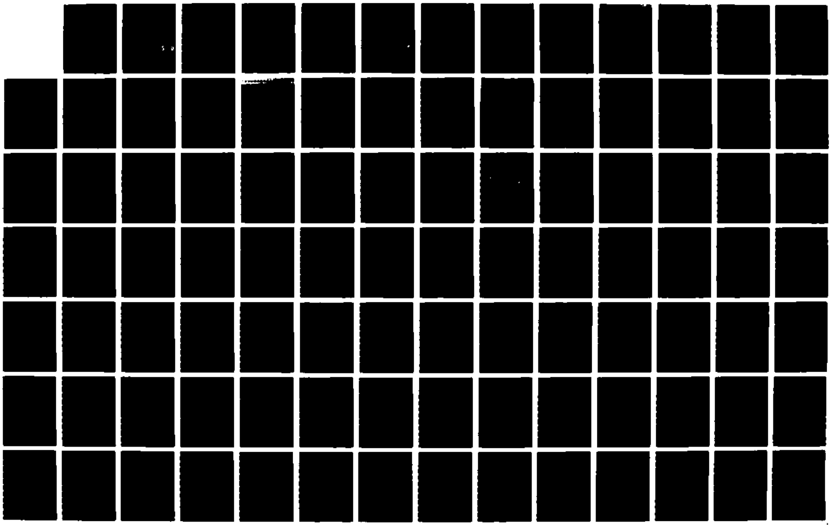

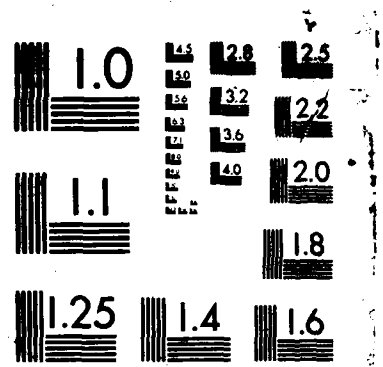

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DETERMINING THE MAXIMUM NUMBER OF RADAR CONTROLLED INTERCEPTOR AIRCRAFT BY A TACTICAL AIR DEFENSE SYSTEM

THESIS

Donald W. Clements
Captain, USAF

AFIT/GST/ENS/87M-5

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Under the 'ideal conditions' currently modeled (no radar/communications jamming, no offensive air-to-air ability for the hostile aircraft), results indicate that multiplication of the control capability of the 'average' weapons controller by the number of controllers available accurately predicts the maximum control capability of the system. The exception to this relationship occurs when the enemy attack is not uniformly distributed throughout the theater. In this case, area saturation effects cause a drop in the number of controlled interceptors. Further work needs to be done to examine the effect of relaxing the initial assumptions that make up this 'ideal' environment.

AFIT/GST/ENS/87M-5

DETERMINING THE MAXIMUM NUMBER OF RADAR CONTROLLED INTERCEPTOR AIRCRAFT BY A TACTICAL AIR DEFENSE SYSTEM

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

Donald W. Clements, B.S.
Captain, USAF

June 1987

Preface

The purpose of this study was to develop a method to determine the maximum number of interceptors that can be simultaneously controlled in a theater tactical air defense scenario. The intercept control is provided by air weapons controllers assigned to the radar systems that make up the Tactical Air Control system (TACS). This value is needed by the Air Force Center for Studies and Analysis as an input variable for their new theater air combat simulation, TAC ALLOCATOR.

Because of the many factors that could possibly affect the maximum number of controlled interceptors, computer simulation was chosen as the methodology to conduct the research. Under the 'ideal conditions' currently modeled (no radar/communications jamming, no offensive air-to-air ability for the hostile aircraft), results indicate that multiplication of the control capability of the 'average' weapons controller by the number of controllers available accurately predicts the maximum control capability of the system. The exception to this relationship occurs when the enemy attack is not uniformly distributed throughout the theater. In this case, area saturation effects cause a drop in the number of controlled interceptors. Further work should be done to examine the effect of relaxing the initial assumptions that make up this 'ideal' environment.

I would like to thank several people without whom this effort would have been almost impossible. Major Joe Litko,

my thesis advisor, and LTC Tom Schuppe, alternate advisor, have both contributed many hours of help, advice, and (most importantly) encouragement for which I am deeply thankful. I also want to thank Capt Ken Charpie for showing me another computer system that was available to run my model. Without that help, my simulation runs would have taken twice forever to accomplish. Finally, I want to thank my wife, Marcia, who managed to raise three daughters, run our home, and still be understanding when I occasionally found some time to be with her.

Donald W. Clements

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Abstract

This research used computer simulation to develop a method to determine the maximum number of interceptors that can be simultaneously controlled in a theater tactical air defense scenario. Intercept control is provided by air weapons controllers assigned to the radar systems that make up the Tactical Air Control system (TACS). Analysis of a research questionnaire indicated that the 'average' weapons controller could simultaneously control either 3.41 or 4.71 flights of interceptor aircraft depending on the range of the interceptor internal radar system (less than/greater than 50 miles against a one square meter target). The computer simulation was built so that the average control capability of the entire theater closely approximated this average capacity.

Under the 'ideal conditions' currently modeled (no radar/communications jamming, no offensive air-to-air ability for the hostile aircraft), results indicate that multiplication of the control capability of the 'average' weapons controller by the number of controllers available accurately predicts the maximum control capability of the system. The exception to this relationship occurs when the enemy attack is not uniformly distributed throughout the theater. In this case, area saturation effects cause a drop in the number of controlled interceptors. Further work

needs to be done to examine the effect of relaxing the initial assumptions that make up this 'ideal' environment.

I. Introduction and Problem Formulation

Introduction

The Joint Staff Officers Guide, AFSC Pub 1, states "Some of the PRIMARY FUNCTIONS of the Air Force are to: ...gain and maintain general air supremacy, ...and to establish local air superiority" (3:Tab I:i). On the "friendly" side of the Forward Edge of the Battle Area (FEBA), these tasks are accomplished by the forward air defense system. The forward air defense system consists of surface to air missiles (SAMS) and interceptor aircraft. The interceptors are controlled by air weapons controllers using either ground or airborne based surveillance radar systems. The efficiency of the air defense system in getting the interceptors engaged with attacking hostile aircraft is a major factor in gaining and maintaining air superiority.

Although many studies have been made concerning different factors of the air defense system, none have attempted to determine system efficiency in terms of the maximum numbers of interceptor aircraft that can be controlled. The validity of this maximum control capacity as a measure of the air defense systems efficiency can be seen after examining the environment surrounding the air defense intercept.

Air Intercept Environment

One of the first factors to consider is the difference in the amount of threat that can be "seen" by the pilot in his interceptor aircraft versus that which can be seen by the weapons controller using his/her surveillance radar. The internal radar capabilities of the interceptor aircraft vary from very limited radar search (such as an F-5) to radar search ranges exceeding 60 miles (such as a F-15). The interceptor radar is also limited in its angle of coverage, not being able to "see" beyond 60 degrees (or less) either side of the nose of the aircraft. In addition, once an interceptor "locks-on" to a target, the aircraft radar then is only capable of giving the pilot information on the "locked" target. (Currently, the only exception to this rule is the Navy's F-14 aircraft.) At this point, the pilot has no information on any other aircraft except those that he can visually acquire. The weapons controller, on the other hand, using his radar system can detect hostile aircraft out to ranges usually in excess of 200 nautical miles in all directions. Using this information, the weapons controller can start directing the interceptor to engagements before the pilot could have detected the hostile aircraft, plan the next and subsequent engagements, and warn of any threatening actions by the hostile aircraft the pilot could not see. These responsibilities place a large workload on the controller and place an upper limit on the number of interceptor aircraft that he can control.

Before the weapons controller can attempt to direct an interceptor to an engagement, the air defense system must first identify hostile and potentially hostile aircraft. This task involves not only identifying aircraft that originate on the enemy side of the FEBA, but also being able to distinguish between the attacking hostile aircraft and the friendly aircraft that may be returning from strikes in enemy territory. Due to the sheer numbers of aircraft involved, the difficulty of the ID task greatly increases as the scale of the conflict approaches the theater level conflict . This job can be made even more difficult by the enemy through electronic jamming of the radar and other sensors used by the air defense system.

After the identification of the hostile aircraft, the job now becomes assigning priorities to targets. There can be many cases where the number of hostile aircraft exceeds the number of interceptors. The controller must decide which hostile aircraft is the most threatening and intercept that one first. In addition, the controller must also recognize the need for follow-on intercepts. He must plan the first intercept to be in an optimal position at its completion for the next intercept. (Similar to setting up the next shot in a billiards game.) The determination of maximum threat involves another whole set of problems, and will not be considered in this thesis.

After assigning the priorities, the actual intercept

involves the solution to a dynamic, three dimensional geometry problem. Given the hostile aircraft's present location, altitude, speed, and direction of movement, the problem is to maneuver the interceptor to a favorable position from which to engage the hostile. This process must be completed in the minimum time while maximizing the interceptor's advantage over the hostile. The intercept problem must continually be updated and re-solved as the hostile aircraft continues to maneuver to either avoid interception or to improve his position for engagement.

Depending on the situation or pre-briefed procedures, the controller can help the interceptor solve the intercept problem in various ways. Close control of the interceptor is the most demanding situation for the controller. During close control, the controller completely solves the intercept problem for all interceptors under his control. The controller provides individualized instructions to each interceptor up to the point of intercept. These instructions include information about the position of the hostile relative to the individual interceptor and directions to the interceptor pilot about the heading, speed and altitude to fly his aircraft. The controller assigns specific hostiles to each interceptor, thus maintaining total responsibility for the air defense in his region.

At the opposite end of the control spectrum, broadcast control is the least demanding situation for the controller. During broadcast control, the controller provides no indi-

vidualized instructions, but provides only hostile aircraft locations based on a standard reference point. The interceptor pilot must then solve the intercept problem based on the hostile location and his own position relative to the reference point. Because each interceptor pilot decides for himself which hostile to intercept, some hostiles may be intercepted more than once while others may not be intercepted at all.

The mid-point of the control spectrum is tactical control. During tactical control, the controller provides each interceptor individualized *information* concerning the hostile aircraft's location relative to the current interceptor location. The interceptor pilot uses this information to solve the intercept. The controller can also help the interceptor decide which hostile to intercept, thus providing some degree of assurance that the most threatening hostile aircraft will be intercepted.

Because the different types of control cause different workloads on the controller, he is able to efficiently control different numbers of aircraft in each situation. The fewest number of aircraft can be controlled during close control, and the most can be controlled during broadcast control. The trade-off, however, is between number of aircraft controlled and the assurance that particular hostiles will be intercepted and engaged.

Radio limitations are another portion of the intercept

environment that can affect the number of interceptors controlled. Currently, all Air Force intercept control is provided via a voice radio link. Although more than one set of interceptors can be controlled on a single radio frequency, confusion may result if too many people try to share a frequency. The optimum situation is the minimum number of interceptors on each frequency, but because of radio limitations this may not be possible. Typical controlling units have only two to five radios available for the air defense mission. The enemy can also confound the problem by jamming the communications links.

Even when the enemy seems to be "cooperating" by not jamming either radar or radio or by not maneuvering to cause constant revision to the intercept problem, the type of interceptor aircraft can affect the the efficiency of the air defense system. An advanced "look-down, shoot-down" interceptor such as the F-15 requires minimal controller help to complete the intercept. Older, less advanced interceptors such as the F-4 or F-5 require more controller help. This is because the less advanced interceptors cannot "see" the hostile on their own internal radar as early as aircraft like the F-15. The earlier the interceptor "sees" the hostile, the less help is required from the controlling radar system. Just as in the case of close control versus tactical or broadcast control, the more control provided by the controller increases his workload and therefore decreases the total number of interceptors he can

simultaneously control.

The sophistication of the controlling radar facility also affects the forward air defense efficiency. Radar facilities range in sophistication from completely manual intercept control systems to highly computer assisted systems. In a computer assisted facility, the computer helps by overlaying graphic displays over the radar returns. The computer can also solve the intercept geometry problem and provide continuous updates to the solution. With increased computer assistance, the controller is able to control more interceptors.

In summary, the maximum controlled interceptor capacity of the air defense system depends on several constraints. The most obvious constraint is the number of controllers available to the system. Another constraint is the amount of jamming (both electronic and/or communications) being used by the enemy. Jamming affects the ability of the air defense system to see and identify the hostile aircraft and to communicate this information to the interceptor aircraft. The type of interceptor aircraft under control also constrains the system. The pilot of a more advanced interceptor needs less help from the controller than the pilot of a less advanced aircraft. The more help required by any one pilot reduces the total capacity of the system. Although this list of constraints is far from complete, it should be sufficient to demonstrate the complexity of the system.

Problem Formulation

Although several models simulate various portions of the air defense system, no one model or study directly investigates the efficiency of the system. Computer simulations such as TAC Brawler simulate the actual engagements between aircraft (22). Other models examine the effectiveness of the system by using the number of aircraft that are able to penetrate the system defenses (16). The Air Force Center for Studies and Analysis is currently developing a new computer simulation model, TAC ALLOCATOR, that uses the maximum number of controlled interceptors as its measure of effectiveness for air defense (11).

In TAC ALLOCATOR, the maximum number of controlled aircraft is broken down into two numbers, C-max and C-min. These numbers are combined together as a weighted average to determine the total controlled aircraft capacity of the air defense system (11). C-max and C-min are defined as follows (36:30-31):

> C-max is the maximum intrinsic control capacity for a baseline system with only good radar (50 NM range against a 1 SQ M target) equipped interceptors in the system. The baseline system has easy geometry and full radar coverage. (C-max is expressed in terms of number of aircraft.)
>
> C-min is the maximum intrinsic control capacity for a baseline system with only poorly equipped interceptors in the system such that full control is demanded until within close range attack parameters (1 NM).

Because C-max and C-min are currently determined from a rough approximation and because the maximum number of controlled aircraft has such an impact on system effectiveness, Studies and Analysis has requested help to more accurately determine these numbers (10).

Research Objective

Determine the maximum number of interceptor aircraft that can be effectively controlled by a forward air defense system. This number should be stated in terms of C-max and C-min.

Subsidiary Objectives

In order to meet the overall research objective, a number of secondary objectives must first be accomplished. These objectives are:

1. Determine the maximum number of interceptors that a single weapons controller (average experience level) can simultaneously control. This number can be obtained through opinion of experts and actual controllers via a research questionnaire (survey).

2. Determine the total number of weapons controllers that will be assigned air defense duties under varying threat levels. This number will be used as one of the variables in the overall experimental design.

3. Determine the effect of attack scenario on the control capacity of the theater air defense system. Is

there a difference in system control capacity when the enemy attack is concentrated in one area versus a uniform distribution of attack penetration? This factor will also be used as a variable in the experimental design.

4. Determine the effect of control facility type on control capability. Again, this is obtained from the survey and is a factor in the experimental design.

5. Determine the relationship between single controller maximum capability and the total system capability. This is the link that 'ties' the single controller capacity to the theater capacity. This is obtained from an analysis of the theater air defense command and control structure and equipment.

Scope Limitations and Assumptions

Because this problem concerns an entire air defense system, the scope approaches a theater level conflict. At this level, the control system can consist of several ground based radar systems and one or more Airborne Warning and Control System (AWACS) aircraft. Although TAC ALLOCATOR works on a 24 hour cycle, a representative time period of 8 hours will be examined, with AWACS being either available or not available during this period. Additionally, all system and equipment operating capabilities and limitations will be modeled using 'generic' data in order to keep the study at an UNCLASSIFIED level. This effort is limited to creating the model that can later be used with actual, 'real-world'

data by Studies and Analysis.

One major assumption of this study is that experience level of any one controller will not affect the outcome of the study. This assumption is valid due to the scope of the problem. Because multiple control systems, each with multiple controllers, make up the overall air defense system, only the average experience of the controllers is important.

A second major assumption is that each individual engagement will not have to be studied. The major objective is to determine the maximum number of controlled interceptors, not the outcome of the controlled intercepts. Using the C-max and C-min numbers generated by this model, TAC ALLOCATOR models the conflict situation and does its own analysis of the engagement outcomes, therefore these results are not needed from this effort.

In order to stress the system and to provide a baseline for the study, a Central European scenario will be proposed. This scenario will only serve to provide a threat level and a representative air defense system, the Tactical Air Control System (TACS). Although the TACS is not unique to the Central European environment, the number of units that make up the TACS varies with the threat level. In this sense, the Central European TACS will be used to define a baseline number of units, approximate distances between units, and radar coverage of the various units. Again, the TACS will be studied with generic numbers, capabilities and locations in order to avoid classification problems and to

make the study relevant (with minor changes) to any scenario or region.

Overview of Remaining Chapters

Now that the problem has been defined and limited, it is necessary to examine more closely the radars and aircraft that will be modeled in order to determine the maximum number of controlled interceptors. Chapter 2 describes in some detail the overall structure of the air defense network, the Tactical Air Control System (TACS) as well as the systems that make up the TACS. These systems include the Airborne Warning and Control System (AWACS), the 407L ground radar equipment, and the new Modular Control Equipment (MCE) that will eventually replace the 407L equipment.

Chapter 3 discusses the methodology that will be used to solve the research question. This methodology includes the use of a survey of weapons controllers that will be performing the air defense mission, the analysis of the survey data to determine the maximum number of interceptors an individual weapons controller can control, and the simulation model that ties everything together.

Chapter 4 discusses the formulation of the simulation model. The actual source code will not be included in this chapter, but rather will be included in Appendix D. Chapter 4 also discusses the extra simplifying assumptions needed as the model was formulated and will explain in general terms how the model works.

Chapters 5 and 6 discuss the results obtained from the model and any conclusions/recommendations that can be derived from these results. The variability of the results and the sensitivity of these results to the input data are also addressed. Chapter 6 concludes with recommendations for further research.

II. Background

Overview

This chapter briefly outlines the radar systems that make up the air defense network in the tactical environment. Air defense involves a complex interaction between manned interceptor aircraft, the radar control system (which may or may not be providing active control to the interceptors), and surface to air missiles (SAMS). Because this thesis is concerned with determining the maximum number of interceptors that can be controlled by the radar control system, discussion and modeling of SAMS is not included. A more detailed description of the modeling of the radar systems, interceptor aircraft, and scenario is contained in Chapter 4.

The purpose of this chapter is to provide the reader with a more complete understanding of the various radar elements that will be modeled in this thesis. This understanding of the equipment used in each system provides the background that will be needed to comprehend how the various systems can or cannot be linked together. This linking together allows for sharing radar information and (possibly) interceptor resources in a synergistic manner.

The reader who has background knowledge of these various radar systems may skip this chapter without any loss of continuity within the thesis. Other readers may wish to "skim" this chapter for overall details and background know-

ledge. If necessary, the reader may refer back to this chapter for information concerning the radar equipment if details of the modeling discussed in Chapter 4 are not understood.

Tactical Air Control System (TACS)

Radar control of air defense interceptors involves a very complex interaction between several different radar systems and the interceptors being controlled. These systems are "tied together" by the Tactical Air Control System (TACS). The TACS "provides the Air Force Component Commander (AFCC) with the means to control tactical air operations and to coordinate joint operations with component forces of other military services" (14:276). Within the TACS, surveillance and air defense is normally performed by ground-based radar systems (AFM 2-7:2-2). These ground-based systems include the Control and Reporting Center (CRC), Control and Reporting Post (CRP), and the Forward Air Control Post (FACP). In addition to the ground-based radar systems, the TACS may also be augmented by airborne radar platforms such as the E-3 Airborne Warning and Control System (AWACS).

Numerous other systems are included in the TACS. Overall command of the TACS is executed by the Tactical Air Control Center (TACC). The TACC is the headquarters for the AF Component Commander, and is responsible for planning and execution of all air operations. Other systems within the

TACS are dedicated to interface with Army command echelons to facilitate Air Force support of ground forces in conflict. The major element in this Army interface role is the Direct Air Support Center (DASC). Another major function of the TACS is control of airlift forces. This job is accomplished by the Air Lift Control Center (ALCC) and its subordinate elements. Tactical Unit Operations Centers (TUOC's) are located at fighter and reconnaisance units, serving as an interface between the units and the TACS. Figure 2-1 shows the relationship between the various TACS components. Further information concerning the structure and function of the TACS and it elements can be found in Air Force Manual 2-7.

407L System Description

The current ground-based radar system within the TACS is the 407L system. The 407L system is a modular system that provides a "mobile communications and electronics system for command and control of tactical air operations" (36:264). Because the 407L system is modular, units of different size and function can be deployed. The CRC is the senior radar unit and is responsible for coordination of all air defense within the TACS area of responsibility (24:3). The next level of radar control is provided by the CRP. One or more CRP's are usually deployed forward of the CRC and extend the radar surveillance and control beyond the limits of the CRC (TACS:264). Normally, the CRP has the same

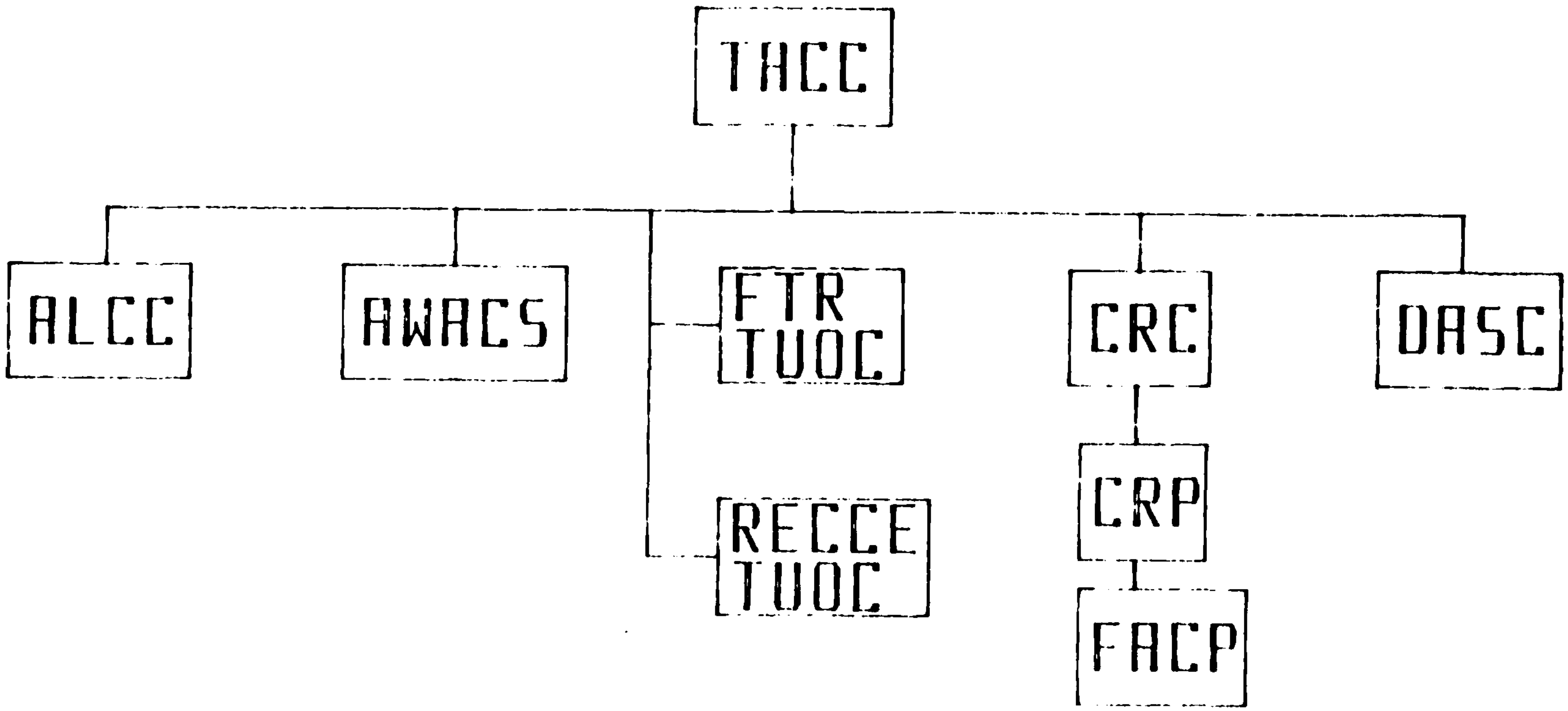


FIGURE 2-1. ELEMENTS OF THE TACTICAL AIR CONTROL SYSTEM
(AFM 2-7)

equipment as the CRC. The primary difference between the two units is mission responsibility. Because the CRP and CRC have almost identical capabilities, the CRP can assume CRC functions if required (12:3-4). The smallest and most mobile of the 407L radar units is the FACP. The FACP is used as a "gap filler" and forward extension of the radar system (12:3-4).

The primary radar of all the 407L units is the AN/TPS-43E three-dimensional radar. This radar is capable of providing radar coverage out to 408km with an altitude accuracy of $\pm$ 305 meters at a range of 100 NM (2:480). Associated with the radar is a modular operations center which contains work stations for two weapons controllers. These radar control work stations are not computer assisted in any way, thus allowing for a manual control environment. The FACP normally is deployed with the radar and one or two of the operations centers, thus providing up to a four controller capability.

Although the radar for the CRC's and CRP's is the same AN/TPS-43E system, the operations environment is different. The TSQ-91 Operations Shelter is a modular shelter that can be connected to other TSQ-91 shelters to provide one large shelter. The radar control workstations within the shelter can be operated in either a computerized or manual mode. In the computerized mode, the radar display scope contains not only the raw radar returns, but also computer generated symbologies that can be used to help maintain tracking and

identification on specific aircraft. The computer can also assist the controller with intercept computations that are constantly updated in order to insure a successful intercept. Normally, four to six work stations in the CRC/CRP are assigned to weapons controllers to perform their functions (20).

Communications within the 407L system consists of a variety of ground-to-ground and ground-to-air communications equipment. The equipment associated with the CRC/CRP's support both voice and digital communications through direct line of sight (LOS) or tropospheric scatter (36:264; 27:2). Each controller has immediate access of up to 15 radio links (covering UHF, VHF, and HF frequency bands) at his/her radar workstation (20). The controller at the FACP has access to 3-4 radio links at his/her workstation (7).

Because the CRC/CRP is computerized, the capability to digitally exchange radar surveillance track information also exists. This allows radar track information processed by one station to be transmitted to and displayed on the radar scopes of another station even though the receiving station may not be able to physically detect the aircraft track with its own radar. Within the 407L system, this digital track data is transmitted from one station to another via the TADIL-B link (TActical Data Information Link). Exchange of digital track data outside of the 407L system requires the interface of the Message Processing Center (MPC) which is

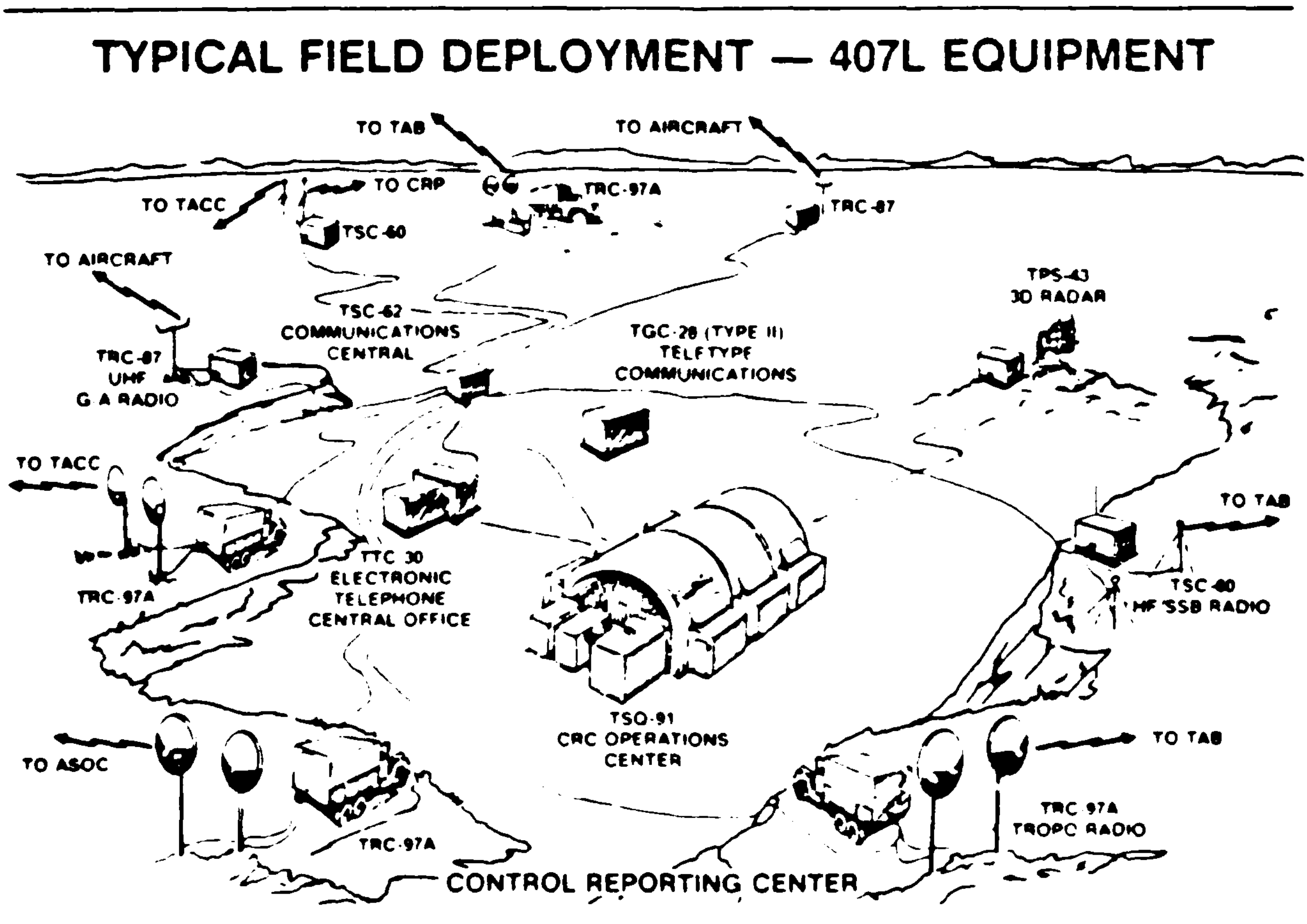


Figure 2-2. 407L System
(Reprinted from 27)

capable of transmitting and receiving information in both TADIL-B and TADIL-A (which is used by Navy/Marine radar units and the E-3). Because the FACP is not computerized, it is not capable of entering the digital track information links.

An example of a typical field deployment of the 407L system to support a CRC/CRP is shown in figure 2-2.

Modular Control Equipment (MCE)

The Modular Control Equipment, MCE, is scheduled to replace the existing 407L system with an initial operational capability (IOC) date of fiscal 1988 (27:3). The MCE can use the same AN/TPS-43 radar, but will use a different operations shelter that contains four radar consoles and more communications and computer equipment than the current radar operations module. With the MCE operations shelter, the only physical difference between the CRC, CRP, and FACP will be the number of shelters used, and the number of personnel assigned to each unit.

Through the use of fiber optic cables, up to five MCE modules can be linked together to form one operational unit. Additionally, the fiber optic cables allow the radar to be remoted up to 2 km from the operations shelters. If more dispersion of the radar is required, separation of up to 40 km is possible through the use of narrow-band secure radio links (38:266). The MCE module is capable of being connected to three separate radars, two of which may be con-

nected via the radio links (27:31).

Each MCE operations shelter contains all equipment (except power and radar) to perform its operational mission (27:17). The radar console is computerized and utilizes a color, touch screen entry display (27:19). Communications within the MCE module allow for connection of up to four UHF, three VHF, and two HF radios. These radios can be used for voice or digital communications and allow the MCE to be "tied into" any existing digital data exchange net without the need for additional interface units (such as the MPC needed for the 407L system) (27:35,37). All communications links are readily available to each controller at his/her console.

Figure 2-3 shows a typical deployment of the MCE.

Airborne Warning And Control System (AWACS)

The E-3 AWACS is a highly mobile, flexible, jam resistant radar platform enclosed in a Boeing 707-320B airframe (5:347). There are currently 34 E-3's in the USAF inventory spread throughout the world in such places as Iceland, Saudi Arabia, Okinawa, and any other location where it is deemed necessary to deploy an E-3. The USAF E-3's are home based at Tinker AFB, Oklahoma. Additionally, there are 18 aircraft belonging to NATO which are home based at Geilenkirchen, Germany and 5 more are due to be delivered to Saudi Arabia.

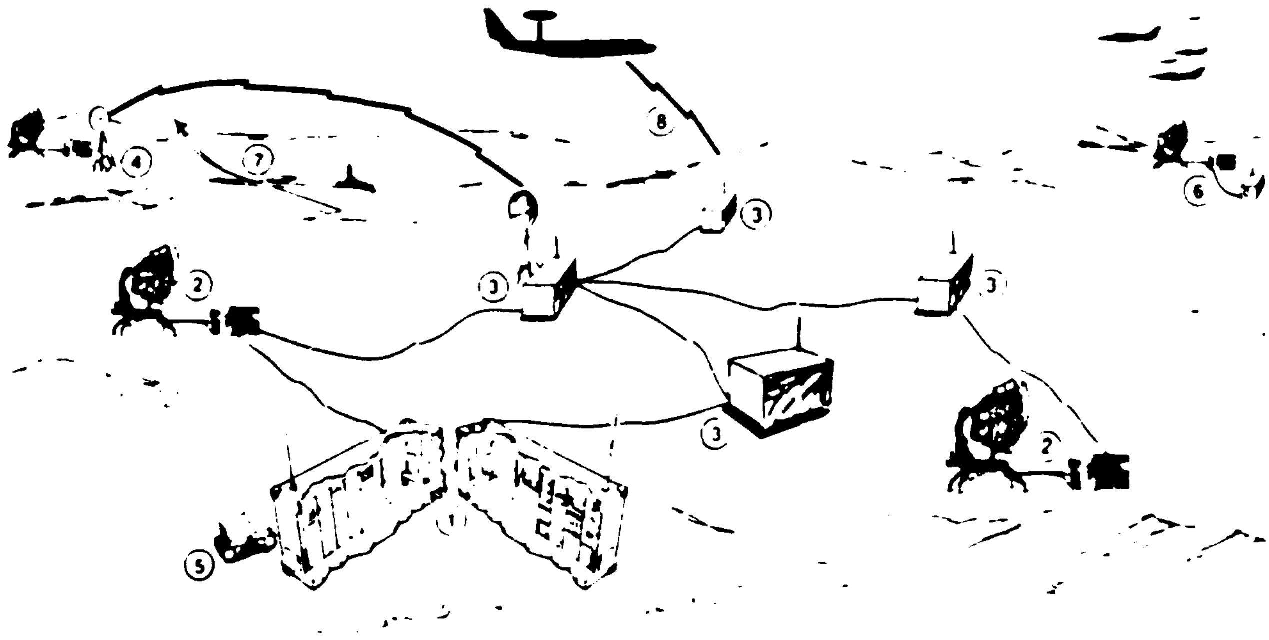


Figure 2-3. MCE System
(Reprinted from 27)

The primary visible feature of the E-3 is the rotating radar dome (approximately 30 feet in diameter and 6 feet thick) which houses the Westinghouse AN/APY-1 pulse doppler radar antenna. The radar operates in the 10 cm wavelength band and is capable of operating in up to 7 different modes in any of the up to 24 operating sectors allowed in one 360 degree scan (13:590). Because the radar's primary operating mode is as a pulse doppler radar, the AWACS is capable of detecting very low flying aircraft up to 200 miles away. It is also capable of detecting and tracking higher flying aircraft at even greater distances (5:347).

Supporting the radar are multiple systems which allow AWACS to function as an airborne C3 platform rather than merely a flying radar outpost. Some of these systems are outlined in Table 2-1.

The normal crew configuration consists of 20 crewmembers, 16 of which operate the mission systems of the AWACS. Seven of the mission specialists are system maintenance technicians. The remaining nine crewmembers each operate one of the SDC's and are either weapons or surveillance personnel or the Mission Crew Commander. Depending on the nature of the mission, the number of weapons and/or surveillance personnel can be adjusted. If necessary, a full or partial battlestaff can also be added. Because of this flexibility, the AWACS can perform duties as either an airborne CRC or CRP as required.

TABLE 2-1. E-3 SYSTEMS DESCRIPTION
(5:347-348)

SYSTEM	CHARACTERISTICS
COMMUNICATIONS	13 Links spanning the HF/VHF/UHF range, capable of providing both clear and secure voice or data links. SATCOM is also available.
COMPUTER	IBM system with a main memory of 800,000 words, and a processing capacity of 740,000 operations.
DISPLAY	Current configuration consists of 9 situation display consoles (SDC's) capable of displaying a region several times larger than the radar volume of the individual E-3. Display area can be expanded for a close up view of a particular region or condensed so that a battle commander can see the entire theatre at once.

Several system upgrades have been identified, and are in progress on the AWACS. The following discussion briefly outlines some of the more important upgrades that will directly affect the capability of the AWACS in the air defense role.

Have Quick. Several of the UHF radios have been modified to perform the fast frequency hopping, anti-jam capabilities provided by Have Quick. The E-3 Have Quick radios are capable of holding the required timing synchronization signal for several weeks and can be used to resynchronize other Have Quick radios (especially useful for fighter air-

craft under AWACS control). Although the E-3 has had Have Quick for the past several years, it is currently upgrading to the newer Have Quick-2 which provides for even faster frequency hopping over a broader range of frequencies (26:99).

<u>JTIDS</u>: JTIDS, Joint Tactical Information Distribution System, provides secure, jam resistant communications through fast frequency hopping, time division multiple access techniques. Currently, all NATO E-3s and three USAF E-3s are equipped with JTIDS. Programs are currently under way to equip all E-3s and several tactical aircraft such as the F-15 with JTIDS. Once this is accomplished, the E-3 and other JTIDS equipped aircraft will be able to digitally exchange data so that everyone will be able to have a more complete picture of the tactical situation. This will be available even if up to 50% of the signal is lost due to jamming (21:101).

<u>Radar Upgrades.</u> A new development contract has been awarded to Westinghouse for an improved radar data correlator. This will give the E-3 an even greater ability to detect and track small targets (29:102).

Summary

This chapter has briefly described the Tactical Air Control System and the radar control elements that currently or soon will comprise the TACS. The ground-based portion of the TACS is made up of the Control and Reporting Center (CRC), Control and Reporting Post (CRP), and the Forward Air Control Post (FACP). Under the current 407L system, the FACP is a manual control facility with up to four radar display consoles. The CRC and CRP are identical in terms of equipment and personnel, but differ in terms of function and responsibility. The CRC is the senior radar element in the TACS and generally has centralized identification authority. The CRP serves the CRC in its assigned subsector of responsibility and can assume the function of the CRC if required.

The upgrade of the ground-based TACS with the Modular Control Equipment (MCE) will not change the functional roles of the TACS elements, but will provide an upgrade in capability. With the MCE, all ground units will have full computerized display and assistance. Additionally, there will no longer be a need for an extra piece of equipment (the MPC) in order to digitally exchange radar track information over any existing data link.

The airborne radar element of the TACS is the E-3 Airborne Warning and Control System (AWACS). Flying at an altitude of 29,000 to 30,000 feet, the E-3 is capable of detecting low flying aircraft at distances up to 200 NM and higher altitude aircraft at greater distances. The AWACS is

fully computerized and is capable of exchanging digital surveillance data with either the MPC or the MCE when that system becomes operational. Several system upgrades are currently in progress that should further enhance the E-3's performance capabilities. The AWACS can perform as either a CRC or CRP as needed by the TACS.

III. Literature Review and Methodology

Overview

This chapter begins by examining past attempts to model the air defense environment. The past studies are considered in light of their relevance to the current problem of determining the efficiency of the air defense system with regard to the maximum number of controlled interceptors. After looking at these past attempts to solve similar problems, the discussion continues with rationale concerning the selection of the measure of effectiveness (MOE's) for this research. In this section, it is shown why numbers such as C-max and C-min are appropriate MOE's. Following the discussion of MOE's, the chapter continues with discussion of the selection of computer simulation as the methodology for the completion of this research. Simulation is shown to have several advantages that make it extremely useful in this thesis effort and other similar problems. The chapter concludes with an examination of the survey used to acquire input data for the simulation effort. This section discusses the development of the survey and how it was selected to gather the required information that was used in the simulation development.

Literature Review

Several attempts have been made to model the air defense environment. While some of these past efforts model strategic air defense and others model the tactical environment, most model the interaction between aircraft (i.e. the actual flying maneuvers), but do not model the effects of the forward air defense system. One such model is TAC Brawler (22). In models such as TAC Brawler, aircraft engagements are modeled from the one versus one scenario up to the few versus few or many versus many scenarios. TAC Brawler increases the probabilities of an interceptor killing a hostile aircraft if the interceptor is "within range" of a radar control facility (22). This increase in kill probability is TAC Brawler's only attempt to model air defense system efficiency. TAC Brawler makes no attempt to quantify the number of interceptors that could actually be controlled by the air defense system, and therefore is not useful in this effort.

Several AFIT theses have also attempted to model some portion of an air defense system. In 1981, R. C. Riecks modeled penetration of bombers and air launched cruise missiles (ALCMs) against an interceptor force controlled by an AWACS aircraft (32). Because Riecks' effort simulated strategic air defense and the attempt to intercept the penetrating bombers at maximum distance from the continental United States, there was no interaction between different radar units as is the case in the TACS. Additionally,

although this study modeled the capabilities of the AWACS radar, it did not look at the effect of weapons controller efficiency and how this factor might affect the number of interceptors that could be controlled.

In 1982, M. W. Grant modeled the relative effectiveness of three levels of Soviet air defense systems against a bomber threat. The first level of air defense involved the use of the Soviet AWACS (SUAWACS) to control the air defense interceptors. Grant found that the number of controllers and the number of interceptors controlled by each controller did affect the number of bombers that were expected to survive (16:95). Grant did not, however, try to find the maximum number of interceptors that could be controlled. In Grant's scenario, the number of interceptors was the limiting factor, and therefore the maximum number of controlled interceptors was not important. Just as in Riecks' study, Grant's research did not model the interactions between different types of radar systems which is important in a tactical scenario.

In 1983, there were three more attempts to model air defense systems. While attempting to model large scale air-to-air engagements, R. J. Bogusch discussed the effect of forward air defense controllers, but did not attempt to include this aspect in his model (6:25-27). As in TAC Brawler, the Bogusch effort is directed at modeling the aircraft versus aircraft arena with little regard for the

control system.

The second effort of 1983 was that of D. W. Hiestand and F. M. Smiley whose scenario involved the use of the Navy's E-2 Hawkeye aircraft (similar to, but smaller than the E-3, AWACS) in the defense of a naval battle group. This research attempted "to develop a computer-based mathematical model which would determine the cardinal threat value of enemy aircraft which were attacking a Navy battle group" (18:x). This was an attempt to automate part of the controller's decision process to determine which threat aircraft to intercept first, and thereby lessen the controller task loading. According to Hiestand and Smiley, this will "allow more efficient processing of information, and decrease the response time of Navy air defense forces" (18:2). Again, there is no direct attempt to determine maximum interceptor control capability, but there appears to be an implicit assumption that controller workload (and therefore, controller saturation limits) directly affects the efficiency of the air defense system.

The third effort in 1983 was by S. A. Hansen and R. S. Price who investigated an automated algorithm for interceptor assignment against specific hostile aircraft (17:ii). In this research, Hansen and Price also looked at the scenario involving the defense of a naval battle group, but concentrated on the determination of which interceptor to assign to intercept a particular attacking hostile aircraft (17:I-1). As in Hiestand and Smiley's

effort, the purpose was to create an automated aid to help the controller with this task in order to reduce his/her workload.

While all of these models have some bearing on forward air defense, none try to solve the problem of determining the maximum number of controlled interceptors. The studies by Hiestand and Smiley or by Hansen and Price are the direct result of the recognized need to increase controller efficiency by decreasing his/her workload, but even these studies make no attempt to find the control limits of the air defense system. In addition, none of the research efforts discuss the relationship between the different types of radar control facilities that are found in the tactical environment.

MOE Selection

Much has already been said about the need to examine the air defense environment from the standpoint of the maximum number of controlled interceptors, but why is this an important viewpoint? It has been already pointed out that the Navy is concerned with decreasing the workload on the controllers in the E-2 Hawkeye and has sponsored research on automating several controller functions to help accomplish this goal (17 ; 18). By reducing the E-2 controller workload, the Navy feels that the controller should be more efficient. An appropriate measure of this increased efficiency could be the ability to control more

air defense interceptors.

Another factor that points to the correctness of using the number of controlled interceptors as a measure of effectiveness is the dilution effect. Dilution refers to the use of concentration and mass when attacking a defense. This is one of the basic principles of warfare, and Air Marshall Guilio Douhet describes its use in air warfare as follows (1:85):

> Keeping together in mass in its operations makes it possible for the Air Force to force its way through any aerial opposition successfully. This is the same principle which governs warfare on land and sea; and therefore the material and moral effects of aerial offensives -- as any other kind of offensive -- are greatest when concentrated in time and space.

In a more recent effort concerning the dilution effect, Andre Murphy examines the penetration of bombers through an air defense network. In his report he states (30:3):

> It is believed the dilution effect depends on the number of penetrators, the number of defensive elements, **the number of simultaneous events that can be processed by the defensive element**, defense detection ranges, bomber speeds, etc. (emphasis added)

For the purposes of this research, it can be seen then that C-max and C-min, representing the maximum number of interceptors that can be controlled by the air defense system, are appropriate MOE's. As was shown in the literature review, models that only represent the interaction between aircraft during engagements take as

given the fact that a controlled interceptor has a higher probability of kill against a hostile aircraft than an autonomous interceptor (6 ; 22). It was also shown that the Navy is concerned with reducing the controller workload by automating some tasks (17 ; 18). When these factors are combined with the effect of air defense saturation as expressed by Murphy and his work on the dilution effect, the maximum number of controlled interceptors becomes an important measure of effectiveness for the air defense system.

Methodology

The process of determining the proper methodology for this effort resulted in the selection of computer simulation as the methodology of choice. Other methodologies (i.e. dynamic programming, response surface, queueing theory, etc.) were considered as possible approaches, but computer simulation was considered to be the best approach to this problem. When selecting computer simulation as the research methodology, it should be realized that the results obtained are not necessarily the "optimum" or even the only solution to the problem. What is obtained is the "consequences of a particular set of input conditions and decision rules applied to a process" (33:2). Additionally several advantages of simulation that are particularly appropriate to this problem are listed by Banks and Carson (4:4).

--Simulation enables the study of, and experimentation with the internal interactions of a complex system, or of a subsystem within a complex system.

--By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.

--Once a model is built, it can be used repeatedly to analyze proposed designs or policies.

--It is usually the case that simulation data are much less costly to obtain than similar data from the real system.

--Whereas analytic models usually require many simplifying assumptions to make them mathematically tractable, simulation models have no such restrictions.

Simulation Procedures. Because computer simulation has been chosen, the problem now becomes how to build the model that answers the question at hand. Figure 3-1 (4:12) illustrates the steps required in a simulation study. The steps outlined in this figure will form the basis for the remainder of this discussion.

At this point, the problem is already stated, and simulation has been chosen as the overall methodology (steps 1 and 2). The next steps, 'model building' and 'data collection' are usually performed simultaneously (4:13). This is due to the large amount of time required for data collection and because the model formulation will often dictate what type of data is required (31:12).

One of the most vital pieces of data for this problem is the maximum number of interceptors that an individual

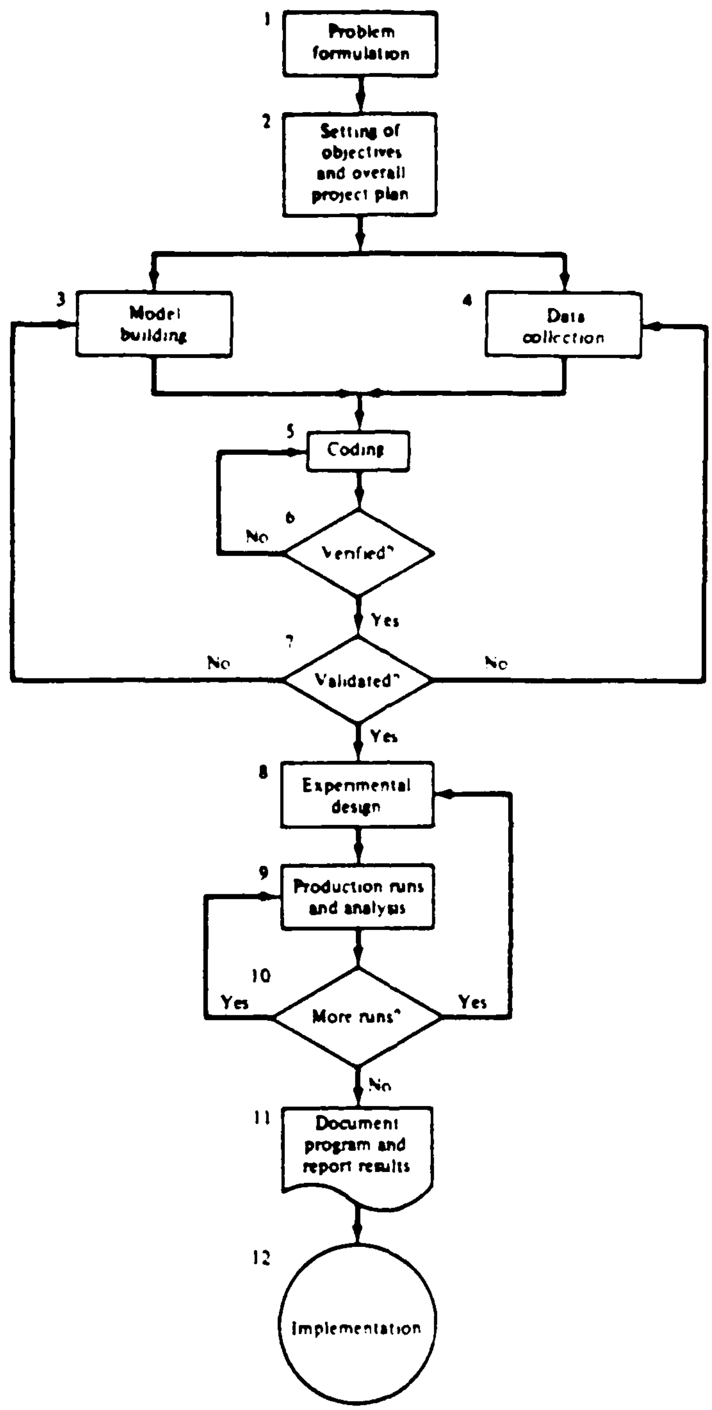


Figure 3-1. Steps in a Simulation Study
(Reprinted from 4:12)

controller can simultaneously control. Current training and evaluation directives dictate the minimum control requirements for a controller in a particular system (Goodrich), but maximum control capability is a matter of individual experience. Because this problem concerns an entire air defense region, it should be possible to assume that one individual's experience does not significantly affect the outcome of the simulation due to the wide range of experience levels that could be present at any point in time. Data concerning average experience was obtained from a survey of individual capability and from expert opinion. The design of the survey is discussed later in this chapter.

Data concerning the capabilities of the radar systems and their interactions is also needed. This type of data is available in both classified and unclassified sources. The sponsor for this research, Air Force Center for Studies and Analysis, has agreed that the initial model can be built with "generic" data so as to avoid classification problems (11). Data concerning radar coverage, number of control positions available, radio links available, degree of computer assistance to the controller, method for exchanging surveillance data between facilities, and resistance to enemy jamming are examples of the capabilities that describe any one radar facility.

Aircraft performance data is another input that the model should be able to use to determine C-max and C-min.

Again, Studies and Analysis has agreed that 'generic' data can be used to formulate the initial model (11). Data needed for this section includes the speed and fuel limitations for the aircraft, the number and type of armament carried, and the internal radar capability of the aircraft itself. Also needed is some idea of the tactics that the interceptor will use when intercepting the hostile aircraft.

After the data is collected and the model designed, it must be coded for input into the computer. This coding can either be done in a special simulation language such as SLAM, or it can be done in a general purpose language such as FORTRAN or PASCAL. There are several advantages and disadvantages to both approaches. Simulation languages such as SLAM provide built in capabilities for such things as event processing and statistics gathering (4:52,104). The general purpose languages are generally faster than the special simulation languages, but they do not have the built in capabilities which make coding easier for the programmer (4:104). Because SLAM is available to Studies and Analysis on a mainframe computer, and readily available here at AFIT on both mainframe and microcomputer, it was chosen as the language for initial coding of the model.

Verification and validation are the next steps in the simulation study (Fig. 1). Verification is the check to determine if the computer code is correct (i.e. doing what the programmer intended) (4:14). Validation, on the other

hand, is checking to determine if the model accurately represents the system being modeled (4:14). In this case, the model can be checked against the approximations of C-max and C-min that are currently being used by TAC ALLOCATOR. If the model significantly differs from the approximations, can a reasonable explanation of the difference be found? This does not imply that validation is conducted only after the model is complete. Validation is an iterative process "normally performed in levels" (31:12). At each level of model development, it can be checked for "reasonableness" of the results by the programmer and by other "experts" who have knowledge in the area being modeled.

The experimental design portion of the simulation study involves placing limits on the number of factors to be varied in the simulation, the period of simulation time and the number of replications (4:14). The actual experimental design of this research is discussed more fully in Chapter 5.

Steps 9 through 12 from Figure 1 involve actions and decisions that are best answered after the simulation model is complete or nearing completion. These steps are also discussed in Chapter 5.

Survey Data

The primary method for gathering data concerning the maximum control capabilities of an individual weapons controller was obtained through the use of a survey. The survey was sent to approximately 500 controllers who are currently assigned to AWACS, CRC, CRP, and FACP radar facilities. A copy of the actual survey instrument is included in Appendix A, and the analysis of the data gathered from the surveys is discussed in Chapter 5.

Before the survey questions are developed, it is necessary to determine if the survey is the proper data collection method to use, and if it is, what is the best method to get the responses from the survey populace. Vernon T. Clover, in his book, Business Research Methods lists several "Conditions for a satisfactory survey" (9:93-94):

> 1. It must be decided definitely and specifically what information is needed in view of the purposes of the project and the uses to which the findings are to be put.
>
> 2. It must be determined that the questionnaire survey technique is the best information-collecting technique available for the particular problem under study.
>
> 3. Certain characteristics of the universe must be known; that is, the geographical area and the persons and/or the other types of cases or units in which the researcher is interested must be decided upon.
>
> 4. It is necessary to establish which type of questionnaire survey technique is most appropriate in this particular project - mail, personal interview, or telephone.

Using these criteria and the facts concerning the numbers and separation of the controllers to be questioned, the mailed survey was chosen to be the proper instrument to be used.

After determining that the mailed survey was the proper instrument, the next major effort was to develop questions that gather the information needed without being ambiguous and or difficult to understand. This process was iterative, and several draft copies of the survey were reviewed by weapons controllers assigned to the Air Force Fighter Weapons School, Nellis AFB, Nevada (8 ; 23). Again, Clover has several recommendations concerning the development of the survey questions. The following list summarizes his recommendations concerning preparation of the survey (9:127-128):

1. Determine all information that is needed to be collected. List this information.

2. The first draft of the survey should have questions that will obtain the listed information.

3. Determine if "filter questions" are needed, i.e. questions that will help identify and locate the respondent. These questions also serve to indicate if this is a correct respondent.

4. The questionnaire should be long enough to gather all needed information, but it should also be kept as short as possible. Ideally, the survey should not take over 15 minutes to complete.

As the survey was developed, its primary purpose of obtaining information concerning the maximum control capability of the individual controller was kept foremost in

mind. The questions were divided into three major sections, the first of which were the "filter questions" recommended by Clover. In this section, the controller was asked about his/her current radar system and current qualifications held. The controller was also asked about any past experience in the weapons control field.

The questions in the second and third sections were identical except for the intended audience and the emphasis on each of the questions. In the second section, the controller was given three separate situations and was asked to respond with his/her perceptions of their own capabilities. The third section was addressed only to the "experts" in the weapons control field (instructors, supervisors, evaluators, etc.). The same questions presented in the second section were again asked, but this time the respondent was to answer with the capabilities of the "average" controller. By asking the same questions, a measure of control was established, allowing for identification of "over-confidence" on the part of the individual controller's perceived abilities. Chapter 5 presents the results and analysis of the survey data.

Summary

While there have been several past efforts to model some portion of the air defense environment, none have directly tried to capture the maximum number of interceptors that could be controlled by the air defense system. This

factor was shown to be a viable MOE to determine system effectiveness because it has been recognized that there is a need to reduce controller workload, and because the dilution effect demonstrates that an air defense system can become saturated. Additionally, several air-to-air engagement models such as TAC Brawler allow a higher probability of kill against hostile aircraft to interceptors that are under weapons control.

Computer simulation has been chosen as the best methodology to place reasonable limits on C-max and C-min. The selection of computer simulation was based on the advantages of simulation when considering a very complex and dynamic system. Given the many varied aspects that make up a theater air defense system, it is a prime candidate for computer simulation.

The decision to use computer simulation does not automatically solve the problem. The steps required when using simulation are outlined in Figure 1. Although the steps outlined in Figure 1 are numbered consecutively, it does not mean that they are performed in that order or that there is a definite starting or stopping point for each step. In act, the entire process is iterative (31:3).

The input data for the model comes from several sources. 'Generic' data describing the various factors which make up the radar units and the aircraft in the scenario are used in order to avoid security classification

problems. The data concerning individual weapons controller maximum control capabilities has been gathered through the use of a mailed survey questionnaire. Care was taken to insure the accuracy of the data collected in this manner.

IV. Model Development

Overview

The purpose of this chapter is to outline the general characteristics of the simulation model developed during this research. This discussion is not intended to present a detailed, line by line description (which would be very dependent upon the SLAM simulation language), but rather a more general algorithmic approach. The prototype model is discussed to outline the general flow of events and the verification and validation efforts that were accomplished as the model was developed. Shifting emphasis to the more complete model, the development of the scenario and the necessary upgrades to the prototype model are then discussed. The chapter concludes with a description of the intercept geometry and a discussion on the determination of intercept heading.

Prototype Model

The air defense environment was modeled using a stochastic, discrete-event simulation framework. In this framework, the variables which describe the state of the system are allowed to change "only at a discrete set of points in time" (4:11). In other words, even though the events which occur in the actual air defense environment may be continually changing, they are modeled as if the changes occur only at specific points in time. At these specified times, the variables which describe the system are updated

to reflect the new overall state of the environment. This framework does not detract from the accuracy of the model because the purpose of this research is not to portray the continual movements of the aircraft through the system, but rather to determine the number of simultaneous controlled intercepts that can occur.

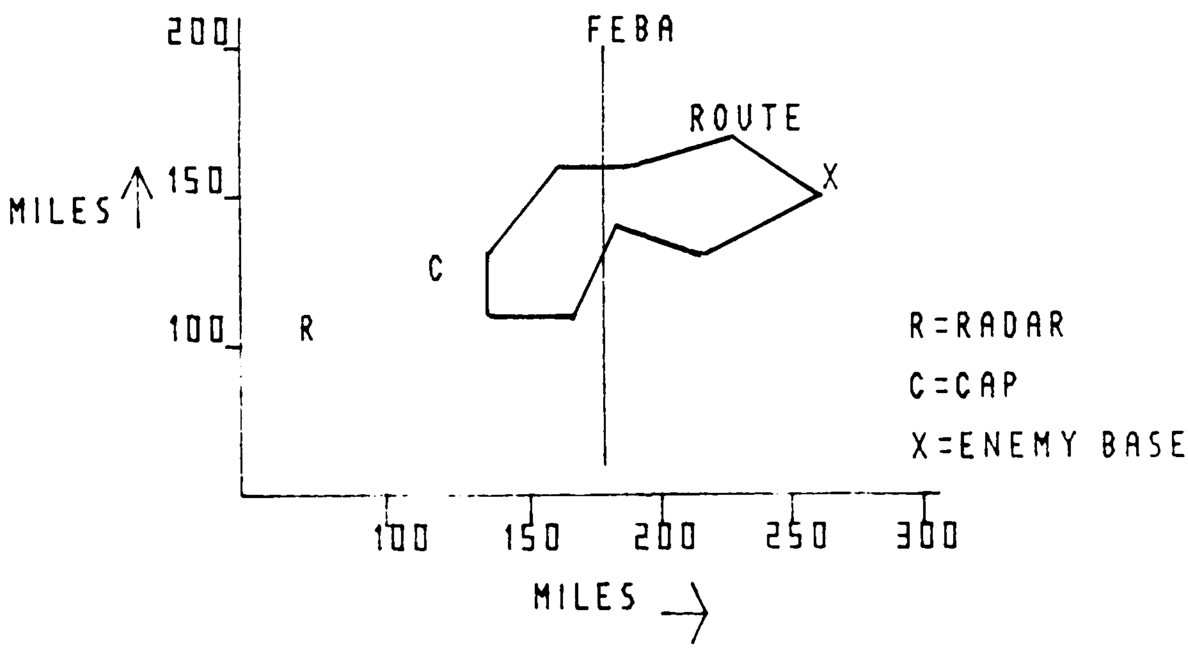


Figure 4-1. Prototype Air Defense Environment

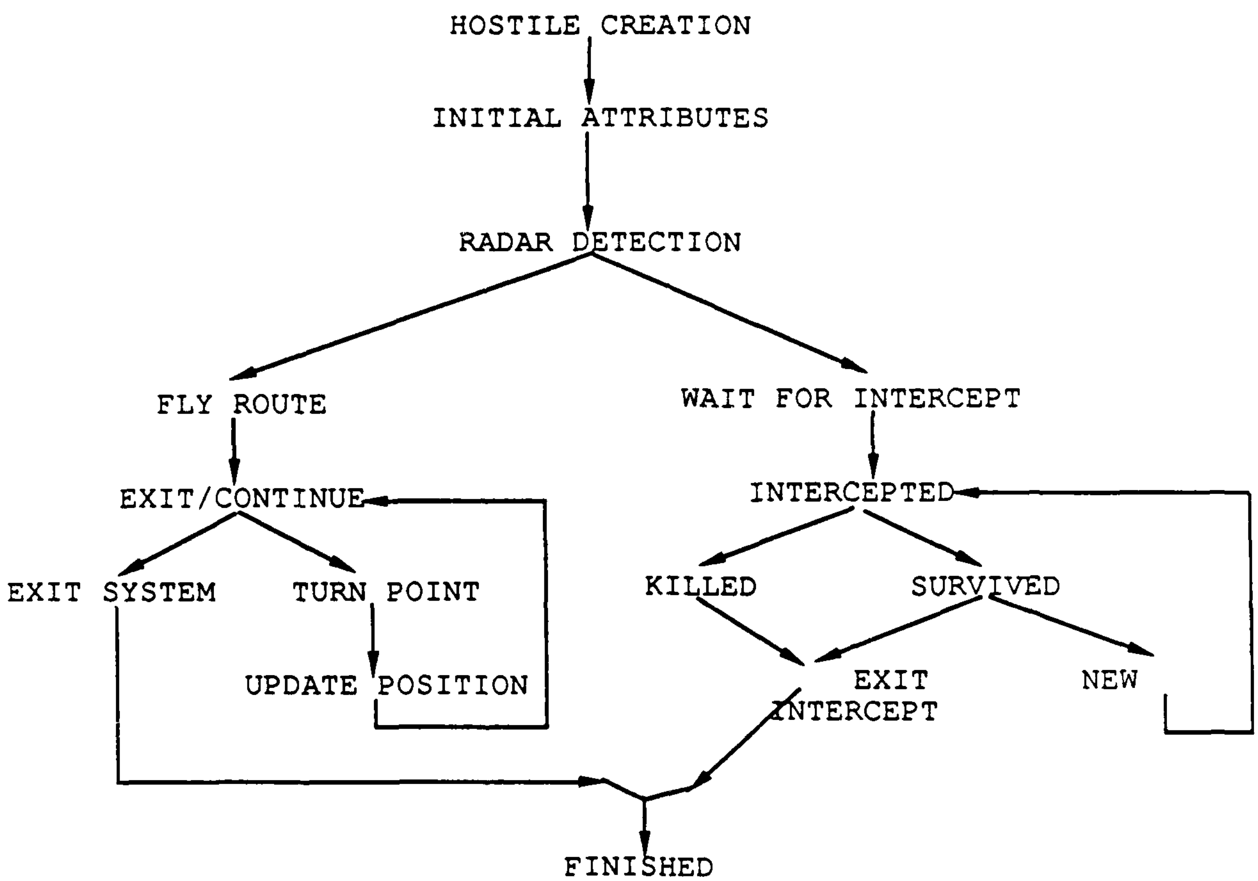
The initial prototype was developed to model one weapons controller using his or her radar system to detect an incoming hostile aircraft and to direct an interceptor to intercept and engage it. A nominal route structure was provided to the hostile to allow it to 'fly' from its point of origin, across, to, and through the friendly airspace and

back to its origin. A grid coordinate system was used to describe the location of the hostile, interceptor, radar system, and airspace boundaries used during model computations. Figure 4-1 illustrates this nominal system.

In both the prototype and the full scale model, the hostile aircraft is treated much the same as a customer in a queueing situation. The hostile aircraft is created, performs certain actions while waiting for the friendly air defense system to "serve" (i.e. intercept) him and then exits the system. If the service does not occur within specified time limits (while the aircraft is still "flying"), it removes itself from the queue and exits without service. Figure 4-2 illustrates, and the following discussion elaborates on this process.

The hostile aircraft is first created and given certain characteristics (or attributes). These characteristics include flying speed, altitude, initial heading (direction of flight), flight size (number of aircraft represented by this one entity), and the current X and Y grid coordinates to indicate position. These characteristics were chosen because they represent actual information presented to the weapons controller tasked with the air defense responsibilities. Appendix E contains a complete listing of all the attributes used to describe the hostile aircraft.

After assigning the initial attributes, the hostile aircraft is then processed to determine the time at which



FIGTURE 4-2. HOSTILE AIRCRAFT FLOW OF EVENTS

radar detection will occur. During this process, the air defense radars are modeled using the radar range equation presented by Skolnik (34:62-63).

The radar range equation is of the form:

$$R^4 = \frac{P\,G\,A\,\sigma\,n\,E}{(4\pi)^2\,k\,T\,B\,F\,\tau\,f\,(S/N)\,L}$$

where
R = maximum radar range (meters)
P = average power of the radar (watts)
G = antenna gain (dB)
A = effective antenna aperture (sq. meters)
σ = cross section of target (sq. meters)
n = number of radar pulses integrated
E = integration efficiency of the radar
L = radar system losses (dB)
F = noise figure (dB)
k = Boltzman's constant
T = standard temperature (290 degrees Kelvin)
B = receiver bandwidth
τ = radar pulse width (seconds)
f = radar pulse repetition frequency (Hertz)
(S/N) = receiver signal to noise ratio (dB)

It should be noted that although several of the parameters are usually expressed in decibels, conversion from decibels to normal numbers is required before calculations are made.

After the maximum range of the radar is determined, the maximum line-of-sight (LOS) distance between the radar and the hostile aircraft at its specified altitude is calculated. Because radar energy propagates line-of-sight, the actual detection of the hostile cannot occur before it is within LOS of the radar. The maximum detection range of the radar and the LOS distances are compared, and the

smallest is chosen as the radar detection range for that hostile. If the route that the hostile is "flying" causes it to change direction before detection occurs, the heading attribute of the hostile is changed to reflect its new heading. Additionally, the position of the hostile aircraft is updated to show the position at which it will enter friendly radar coverage. The time that the radar detection will take place is also determined, and a "radar detection event" is scheduled to occur at that time. Again, the discrete-event nature of the simulation shows through at this point. It is not necessary to model the motion of the hostile aircraft prior to its radar detection because the air defense network cannot do anything to intercept it until it is detected by the system.

After the hostile is detected, it is split into two identical copies for ease of modeling. One copy continues to "fly" its normal route across friendly airspace and eventually back to its home base. The other copy is placed in a "waiting line", or queue, waiting to be intercepted by the friendly air defense system. When both an interceptor and a controller are available, the interception process is started. If the copy of the hostile aircraft that is "flying" through the system has changed its position prior to the intercept being initiated, these changes are updated on the copy that was placed in the queue. Once the intercept process has begun, the copy of the hostile in the waiting queue is removed from that file and placed in

another file to indicate that the intercept process is under way.

While one copy of the hostile aircraft is either waiting to be intercepted, or is being intercepted, the other copy continues to 'fly' through the system. At each turn-point along its route, the position of the hostile aircraft is updated and the heading to the next turn-point is calculated. Additionally, the time until the next turn is calculated so that the next 'turn event' may be scheduled. If the total time that the hostile aircraft has been flying exceeds the amount of time required to complete its entire route, the hostile is removed from the system and 'lands' at its home base.

As was mentioned earlier, in order to start the intercept process, there must be both an interceptor and a controller available to direct the intercept. In this simulation, the friendly interceptor is modeled somewhat like the hostile aircraft. The friendly aircraft is created and given certain attributes such as number and type of missiles available, a starting CAP (Combat Air Patrol) location, and speed of flight. Until the interceptor is needed for an intercept, it is placed in a holding file much like the hostile's waiting file. While the interceptor is being used, it is place in an 'engaged' file. Unlike the hostile aircraft, the friendly does not need a duplicate copy made for processing. This is because the friendly does

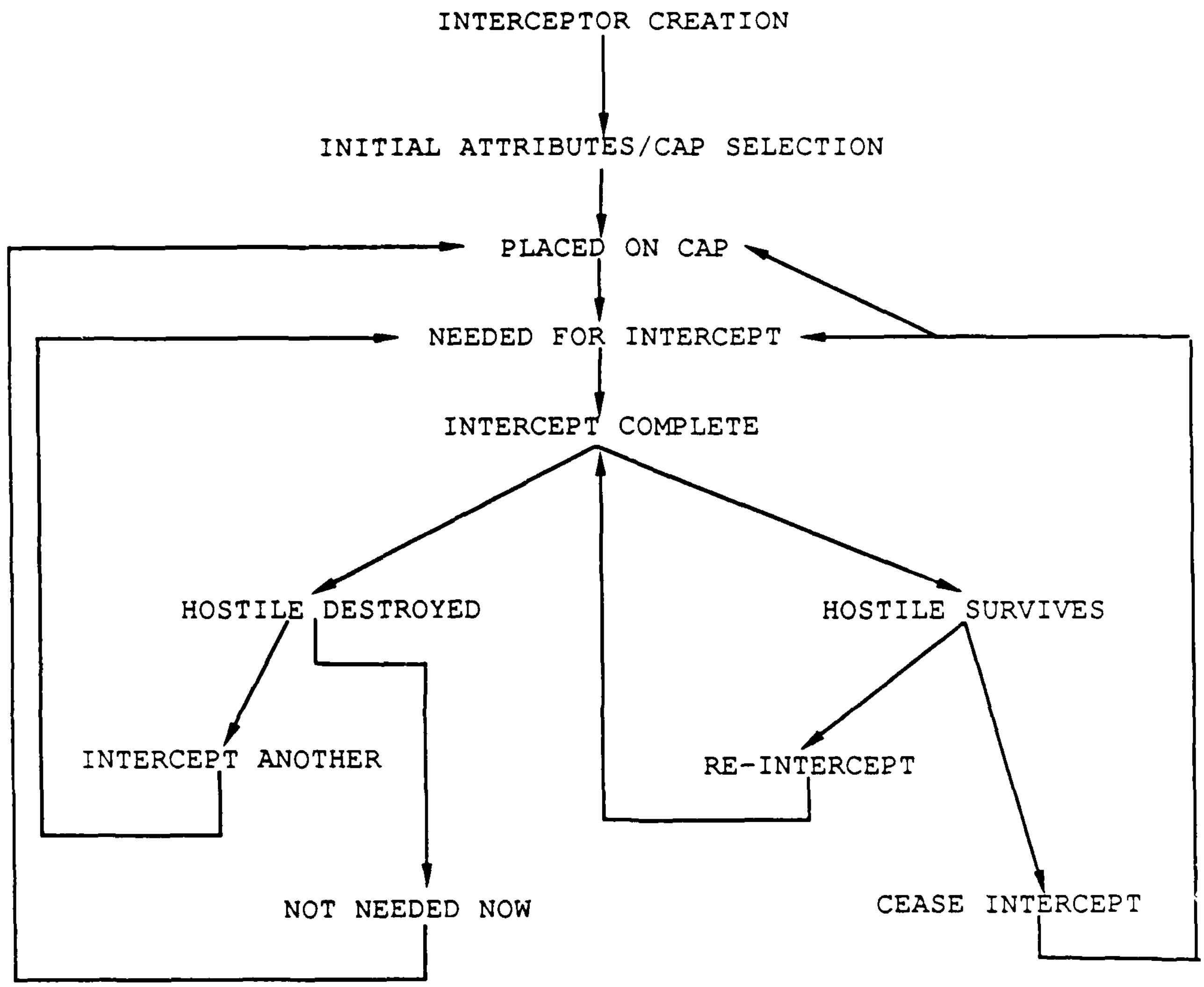


FIGURE 4-3. INTERCEPTOR FLOW OF EVENTS

not 'fly' a specified route, but rather responds to the location of the hostile aircraft as required to complete the intercept. After completion of an intercept, a check is made to determine if that interceptor is needed immediately, or if it should return to its CAP location. Figure 4-3 illustrates the events used to model the friendly interceptor.

Verification and Validation

Verification and validation was a continuing process throughout the development of the model. Although these functions often overlap, they are two distinct processes. When verifying the model, the model builder is checking to insure that the logic of the computer model code is performing as expected. In other words, are the calculations and other actions resulting in the expected or proper results? When validating the model, the modeler is checking to insure that the model accurately represents the system being modeled. This is accomplished by critically examining the assumptions that the model is based upon, by examining each section of the model as it is added to insure that it is an accurate representation of that portion of the entire system, and by examining the results of the model when it is complete. If the final results are totally 'surprising', the modeler must determine if a logical explanation for these results can be found. If an explanation of surprising results cannot be found, it does

not mean that the model is wrong, it only implies that the modeler should critically examine the model to insure its correctness. Throughout the validation process, the modeler may wish to employ the use of an "expert" in the field being modeled. This is especially true if the modeler does not have much personal expertise in the system being modeled.

The air defense model for this research was built modularly. The initial prototype model had but one hostile flying its route through the system and landing back at its home base. After this was completed, the interceptor was added and the intercept and engagement process was checked. During most of this process, the author served as the expert. This was possible because of the author's extensive background as a weapons controller. Additional expertise in the air-to-air engagement between the aircraft was provided by Major Dennis Miner, a former aggressor pilot in the 64th Aggressor Squadron, Nellis AFB, Nevada (25).

The final major step in developing the model was the expansion from one hostile aircraft being intercepted by one interceptor under the control of one weapons controller to multiple hostile aircraft being intercepted by multiple interceptors under the control of multiple controllers. The primary difference between this model and the prototype models is the allocation of interceptors and controllers to intercept the individual hostile aircraft. This allocation is performed through a series of conditional checks that are

scenario dependent. Changes in the scenario require changes to be made in the allocation "rules" for the model to behave correctly. Again, the modeler served as the expert when validating this portion of the model.

Scenario

The scenario chosen for this research is illustrated in Figure 4-4, and could be representative of any number of theater conflicts. As a baseline, however, a Central European theater formed the basis for the scenario. This theater was chosen because of the expected much greater number of hostile aircraft than interceptors and because of the number of types of radar units that make up the European TACS. If the assumption is made that there are more interceptors available than the total number of controllers can effectively control, the maximum number of controlled interceptors becomes the limiting factor in attempting to intercept the hostile aircraft.

The locations of the radar units and interceptor cap points were chosen to reflect general positioning considerations. The interceptors on cap are assumed to be performing a 'lane defense' type of defense. In this defense, the interceptors are responsible for defending against hostile aircraft penetrating their lane or zone. (This can be compared to a defensive back in football who, in a zone defense, is responsible for covering receivers within his zone.) The distance between the caps varies

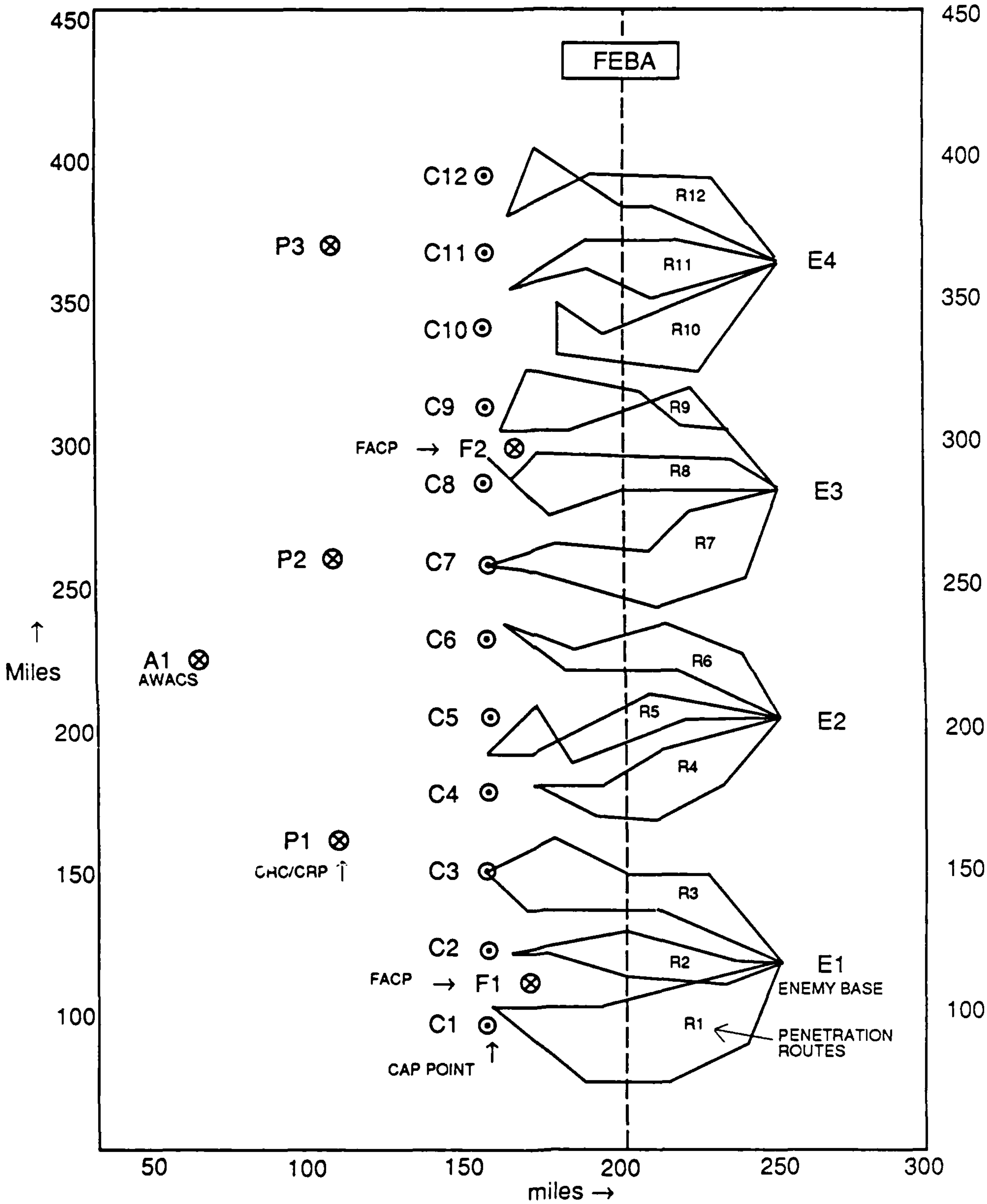


FIGURE 4-4. SCENARIO

between 20 and 30 miles, and although the interceptor is primarily responsible for defending against hostile aircraft within his lane, the interceptor can be used to intercept hostile aircraft in either adjacent lane if required.

The radar locations are also based on general positioning considerations. A FACP, being the smallest and most mobile of the radar units, is positioned closest to the FEBA. The CRC/CRPs are located further behind the FEBA because of their lack of quick mobility compared to the FACP's and because of their overall responsibilities, but still close enough to provide adequate warning of approaching hostile aircraft. The AWACS can be positioned further behind the FEBA because of its extended line of sight due to its orbit altitude. Another factor considered when placing the AWACS is the fact that the AWACS is considered to be a prime target for hostile action. By placing the AWACS at an extended range behind the FEBA, a measure of protection is provided without seriously degrading the AWACS capability.

The hostile aircraft penetration routes were chosen only to indicate possible tactical considerations which might be employed by the hostile forces. By avoiding direct, straight-line penetration routes, the intercept problem is complicated, possibly requiring multiple updates of interceptor heading before interception can occur. For ease of modeling, the penetration routes were selected to

exactly correspond to a cap location. This made the allocation rules easier to formulate, but was not necessary for the actual implementation of the model.

Intercept/Engagement Considerations

One primary task that a weapons controller must accomplish when directing interceptor aircraft against the hostile aircraft is the determination of the intercept heading. For C-max type interceptor aircraft (such as the F-15), this task may be no more than informing the pilot where the hostile is and letting the pilot use his interceptor radar to detect the hostile aircraft and track it until the intercept can be accomplished. For C-min type interceptor aircraft (such as the F-16), the controller must provide more information and may have to provide the intercept heading to the pilot. In either case, an intercept heading must be computed and the interceptor flies along this course until the hostile aircraft can be engaged by the interceptor.

During the time that the interceptor is maneuvering into engagement position, the controller is concerned with providing information concerning the hostile aircraft movements, as well as information concerning other hostile aircraft who may pose a threat to the pilot of the interceptor. In this model, this controller action is represented as the using of a unit of the controllers 'control resource'. If, for example, the controller is

capable of controlling five simultaneous intercepts, he is modeled as having five units of control resource. Each time the controller is needed to control an interceptor, a unit of the resource is "seized", and that unit is not available again until the engagement process is complete. The engagement process is considered complete when either the hostile aircraft is killed or it exits the system due to the completion of its route. When all the control resources are being used, that controller cannot control another interceptor until at least one unit of resource is released. Chapter 5 discusses the formulation of the number of control resources available for each controller in this model.

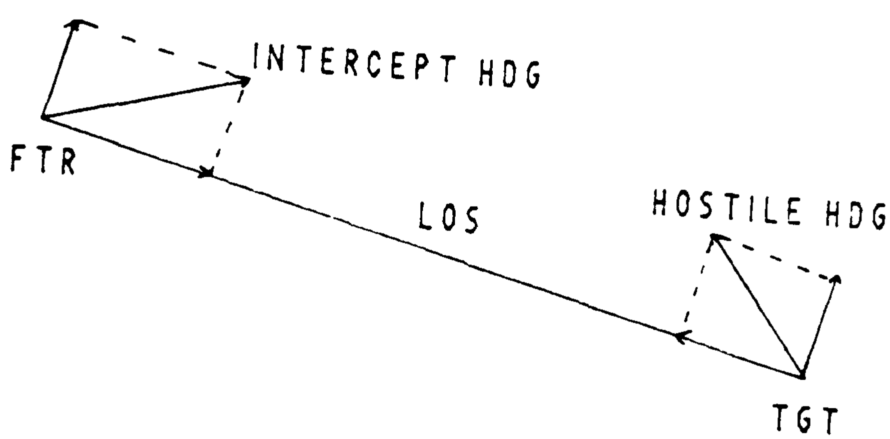


Figure 4-5. Intercept Geometry

Because the controller resource is "tied up" until the engagement process is complete, the time required to

complete the process becomes very important. The time that the interceptor is maneuvering until the actual engagement begins is a minimum if the intercept heading computed is the most direct route available. This geometry is illustrated in Figure 4-5.

In the intercept geometry illustrated, the problem is to compute the intercept heading given the hostile aircraft's current heading and speed and the interceptor's speed. The hostile aircraft's speed and heading can be obtained by observing its past motion and measuring the distance it travels in a given time period. The determination of the intercept heading is a relatively simple problem if the hostile aircraft's velocity vector is broken into a component along the line between the interceptor and hostile aircraft's current position and another component perpendicular to the first component. The interceptor matches the component perpendicular to the line joining the two aircraft, and any remaining velocity is directed towards the hostile aircraft along the line joining the aircraft. The resultant vector is directed along the intercept heading. The magnitude of the interceptor's velocity vector is equal to the interceptor's speed. This speed is set to 1.2 times the hostile aircraft's speed up to a maximum limit imposed by the interceptor's maximum speed.

The time until the intercept occurs is computed by adding the magnitudes of the velocity components directed along the line between the aircraft and dividing this speed

into the distance currently separating the aircraft. This time is then reduced by the time required to fly the distance remaining after weapons can be fired, and the actual engagement begun. The weapons employment ranges used in this model are obtained by random draw between typical limits of the AIM-7 Sparrow and the AIM-9 Sidewinder missiles (25). Appendix E provides the performance data used for the missiles, as well as the aircraft and radar equipment modeled in this effort.

Summary

This chapter has described the development and implementation of the model used in this research. The model was developed in stages, adding complexity and necessary components as required. At each point during the development, the model was checked for accuracy of computations and detail. The modeler's expertise as a weapons controller was used throughout development in addition to expertise obtained from a former aggressor pilot who provided details concerning the weapons employment process.

The final, full scale model was an extension of the prototype model with the primary differences being the number of interceptors, hostiles, and intercepts processed as well as the allocation rules which determined the choice of interceptor and controller used against each individual hostile aircraft. The scenario chosen to run the model was

based upon a Central European scenario, with the interceptors placed in lane defense caps. The radar units were placed in positions that would be 'normal' relative to the FEBA and each other.

The intercept process was computed from the geometric relationship between the interceptor and hostile aircraft. By breaking the hostile aircraft's velocity vector into components along the line of sight between the aircraft and perpendicular to this line, the intercept heading could be calculated. The time to intercept comes as a result of the intercept heading and the weapons employment ranges of the interceptor used in the engagement.

V. Analysis of Results

Overview

This chapter presents the analysis of the results obtained during this thesis effort. Included in this discussion is the analysis of the input data obtained from the research survey as well as the analysis of results obtained from the simulation model. The experimental design used to determine C-max and C-min is presented, and comparisons between the two variables are drawn where appropriate. Detailed listing of the data and the full analysis results are provided in Appendices B and D.

Survey Results

As discussed in Chapter 3, the survey instrument was divided into three sections and was addressed to two basic populations. These populations were the basic qualified weapons controllers and the "expert" controllers (i.e. the instructors, evaluators, and supervisors). Both groups were asked to provide insight into what they thought were their own individual control capabilities, and the "experts" were asked to describe the "average" controller's capabilities. Out of approximately 500 surveys that were sent, a total of 169 were returned. "Expert" responses accounted for 112 of the 169 returned, and 57 responses were obtained from basic qualified controllers. The distribution of the returned surveys with regard to radar system type is as follows: 129 returned by AWACS controllers, 30 returned by CRC/CRP

controllers , and 10 returned by FACP controllers.

Based on the request of Tactical Air Command Headquarters staff (19; 35), the simulation model only used the capabilities of the 'average' controller as provided by the 'experts' as its input data. This data is summarized in Table 5-1.

Table 5-1. Average Weapons Controller Maximum Control Capability

	AWACS	CRC/CRP	FACP	Overall
C-max	4.61	4.89	5.50	4.71
C-min	3.40	3.39	3.50	3.41
Combined	3.83	3.72	4.50	3.85

Although the data obtained from the FACP controllers appears to be significantly higher than the corresponding data from the other two radar types, this is probably not the case. As noted above, only 10 responses were received from FACP controllers out of the total 169 returned. Of these 10 responses, only 6 could be used in the above computations. This is compared to 106 responses from either AWACS of CRC/CRP controllers. When this difference in sample size is considered, there is no statistical difference between the responses from the different radar units.

The process used to convert this data to a form usable in the simulation can now be described. In the simulation,

the ability of one controller to control one flight of interceptor aircraft is modeled as a single unit of a "control resource". Each controller is provided with several units of this control resource up to an average amount. Because the resource can only be given to the controllers in integer amounts, no single controller can exactly match the "average" controller capability described above. It was determined, therefore, to try to match the overall system control capability by providing different levels of individual control and averaging this capability throughout the system. Tables 5-2 and 5-3 summarize the control capabilities of the controllers used in the simulation scenarios.

Table 5-2. C-max Scenario Control Capabilities

	AWACS	FACP1	FACP2	CRC1	CRC2	CRC3
CONTROLLER 1	4	5	5	4	5	5
CONTROLLER 2	4	5	5	4	5	4

SYSTEM AVERAGE: 1 CONTROLLER/RADAR -- 4.667
2 CONTROLLERS/RADAR -- 4.583

Table 5-3. C-min Scenario Control Capabilities

	AWACS	FACP1	FACP2	CRC1	CRC2	CRC3
CONTROLLER 1	3	4	4	3	4	3
CONTROLLER 2	4	3	4	4	4	4

SYSTEM AVERAGE: 1 CONTROLLER/RADAR -- 3.500
2 CONTROLLERS/RADAR -- 3.667

Although not used as input data for the simulation, other interesting side notes come to light from further examination of the survey. The most interesting of these is the confidence of the basic qualified controllers in their own ability to control aircraft. By comparing the "average" controller capabilities obtained from the experts to the basic controller's self image, it appears that either the experts have a more conservative view of the overall capabilities or the basic controller has an inflated view of his/her abilities. Table 5-4 summarizes the basic controller's self perceptions.

Table 5-4. Basic Weapons Controller Maximum Control Capability (Self Perceived)

	AWACS	CRC/CRP	FACP	Overall
C-max	6.23	6.25	8.25	6.38
C-min	4.55	4.75	7.12	4.77
Combined	5.10	4.75	7.50	5.19

When both populations are combined into one larger population, and the overall self perceptions of their abilities are examined, the maximum control capability again increases. These results are summarized in Table 5-5.

By using the results obtained from the experts concerning the "average" controller, the most conservative estimates of maximum control capability has been obtained given the input data. Based upon comments provided by instructors at the USAF Fighter Weapons School (8:23) during

the development of the survey, even this conservative estimate may be somewhat inflated. This is always a possibility when using survey data that requests "personal feelings", but it must be assumed that the responses to the survey were provided in good faith and were the best estimate that the respondent could provide.

Table 5-5. Overall Weapons Controller Maximum Control Capability (Self Perceived)

	AWACS	CRC/CRP	FACP	Overall
C-max	6.42	6.53	7.40	6.50
C-min	4.89	5.13	6.05	5.00
Combined	5.35	5.33	6.50	5.42

Experimental Design

This thesis effort actually attempted to answer two questions rather than one. These questions were to determine values for C-max and C-min. Although related, these are two separate values, each of which is related to its own set of controller capabilities obtained from the research survey. As mentioned in Chapter 1, there are many different variables that could reasonably be expected to affect the value of either C-max or C-min. In an effort to limit the size of the problem domain, four factors were chosen as being the most likely factors to help determine the value of C-max/ C-min. These factors were chosen based upon the author's experience as a weapons controller. The factors chosen were: 1) AWACS availability (yes/no), 2)

ground radar type (407L/MCE), 3) number of controllers dedicated to air defense at each location (1/2), and 4) hostile aircraft attack distribution (uniform/concentrated along one axis).

The availability of the AWACS was chosen as a factor because of the capabilities of the AWACS radar as described in Chapter 2. By the mere fact that the AWACS radar is positioned at an altitude of approximately 30,000 feet, it is capable of detecting and tracking aircraft that a ground radar could not possibly detect until much later. This provides much earlier warning of the approaching hostile aircraft, and more efficient use of the available interceptors can be made.

The type of ground radar equipment affects the ability of the radar units to digitally exchange surveillance data. Under the current 407L configuration, the FACP cannot enter into any data link network thereby effectively isolating the FACP in its area of responsibility. With the implementation of the MCE, the FACP can directly enter the data links and could more easily share its load if events dictated this need.

Although each radar unit is assigned more than two controllers, it is unreasonable to expect all controllers to be dedicated to air defense mission support. Other missions which may require weapons controller tasking include close air support, air interdiction, offensive counter air, aerial

refueling, and air traffic control. Given the proper set of circumstances or events, any individual controller may be tasked with one or several of these tasks at any given instant.

Because C-max and C-min are maximum numbers of controlled interceptors in a theater, the enemy attack distribution plays an important role. If the attack is uniformly distributed throughout the theater, it should be reasonable to assume that controller saturation occurs over the entire theater at approximately the same time. If, however, the enemy chooses to attack primarily in one or more areas, those areas become saturated much earlier than the rest of the theater. When the air defense system is saturated at the point(s) of attack, and no attack is occurring in the other area(s), the theater is effectively saturated and C-max or C-min has been achieved.

The combination of these four factors, each of which is examined at two different levels comprises a 2^4 factorial experiment. In this design, there are 16 different possible combinations of factors and levels. Because two different experiments needed to be accomplished (determination of C-max and C-min), simulation of 32 different design points had to be accomplished.

When performing an experiment of this type, an important consideration is the measurement and minimization of experimental error. There are two different types of error that must be considered. Type 1 error measures the

probability of the experiment to reject as false a conclusion that is in fact true. Type 2 error, on the other hand, measures the probability of the experiment not to reject false conclusions (28:21). It is usually convenient to set a particular Type 1 error level acceptable (significance level) for the experiment and to make enough replications of each experimental design point to insure that false conclusions are not accepted (power of the test) (28:22).

The determination of the number of replications of each design point can be made in at least two different ways. The first way is to determine what difference in mean response needs to be recognized. With this information and an estimate of the variance of response data, the experimenter can use various operating characteristic curves to determine the number of replications required to achieve a given power of the test. The second method is to arbitrarily choose the number of replications to be run based upon outside constraints such as time or resources. The power of the test is then determined based on the actual number of replications run. In this research, the number of replications was limited to two replications for the determination of C-max and three replications for C-min. These choices were made due to limited computer processing time available for each run. The power of the experiment with these replications will be presented later in this chapter.

Experimental Results

Tables 5-6 and 5-7 summarize the results of the experiments to determine C-max and C-min. In both tables, the four factors of the experiment are designated AWAC, FACP, CNTRL, and ATK, each of which is coded either 0 or 1. For the AWAC factor, 0 represents no AWACS available and 1 represents AWACS availability in the scenario. The 0 FACP coding represents 407L configuration of FACP equipment, and 1 represents MCE equipment configuration. The 0 CNTRL coding represents the situation where only one controller is available per radar location for air defense control, and the 1 coding indicates two controllers are available. The ATK coding of 0 represents a uniform distribution of the hostile attack, whereas the 1 indicates that the attack is concentrated in one area (in this scenario a triangular distribution with the maximum concentration near route 8).

An examination of both tables reveal the majority of the conclusions that can be drawn at this time. In both cases, the most dramatic increase in experimental value occurs when there are two controllers available rather than one. This is not surprising. What is surprising, however is that there is generally not a direct doubling of the response. This can be explained when the control capabilities of the controllers are considered. Although the number of controllers is doubled, there may not necessarily (or even usually) be a doubling of the control capability.

Table 5-6. C-min Results

AWAC	FACP	CNTRL	ATK	C-MIN	TOTAL POSSIBLE
0	0	0	0	18	18
0	0	0	1	18	18
0	0	1	0	37	37
0	0	1	1	37	37
0	1	0	0	18	18
0	1	0	1	18	18
0	1	1	0	37	37
0	1	1	1	34	37
1	0	0	0	21	21
1	0	0	1	21	21
1	0	1	0	41	44
1	0	1	1	42	44
1	1	0	0	21	21
1	1	0	1	21	21
1	1	1	0	41	44
1	1	1	1	40.667	44

Table 5-7. C-max Results

AWAC	FACP	CNTRL	ATK	C-MAX	TOTAL POSSIBLE
0	0	0	0	24	24
0	0	0	1	24	24
0	0	1	0	47	47
0	0	1	1	43	47
0	1	0	0	24	24
0	1	0	1	24	24
0	1	1	0	47	47
0	1	1	1	45	47
1	0	0	0	28	28
1	0	0	1	28	28
1	0	1	0	54.5	55
1	0	1	1	47	55
1	1	0	0	28	28
1	1	0	1	28	28
1	1	1	0	55	55
1	1	1	1	50	55

Although not significant in all situations, there is some evidence to indicate that both C-max and C-min behave as predicted in the face of a concentrated attack rather than a uniform attack scenario. In both experiments, the values for C-max and C-min show a decrease when the attack is concentrated in the two controller, MCE equipped scenarios. In the case of C-max and the addition of the AWACS, this decrease is quite large (from 55 to 50). ANOVA results (presented in Appendix D) also support the conclusion that attack scenario is significant.

Perhaps the most significant result is that the control capabilities directly predict the values for either C-max or C-min except where the attack scenario causes some decrease. Excepting the attack scenario, C-max or C-min generally equaled the total possible control capability. This roughly corresponds to the present method used by USAF Studies and Analysis to predict these values. There is one note of caution to be applied however. Several assumptions were made in the development of this model that may not be appropriate in the 'real world'. One of these assumptions was the lack of any type of communications or radar jamming by the hostile forces. Another critical assumption was the uniform radar detection ranges and the ability to continuously track a hostile aircraft once detected. Other assumptions were made and the relaxation of any one of them may cause the values of C-max and C-min to vary. Therefore, this experiment should be considered a fixed effects rather

than a random effects model.

Power Calculations. As mentioned earlier, the power of the test (or experiment) is related to the the number of replications run and the magnitude of difference in results that needs to be detected. This is due to the amount of error that is acceptable while wishing the test to reject false conclusions.

In this research effort, the simulation runs to determine C-max and C-min were run on different computer systems. The models run on both systems were exactly the same except for the control resource allocations that correspond to either C-max or C-min. The C-max runs were made on a VAX 11/780 using a VMS operating system. These runs were processed in a batch mode and were limited to a maximum of 90 minutes of CPU time. Due to the number of hostiles created and the size of the simulation model, this 90 minute time limit allowed only two replications of each design point to be made. (Run times for two replications varied between approximately 70 and 80 minutes.) The C-min runs were made on an Elexi computer using a UNIX operating system. These runs were made interactively and did not have a CPU time limit restriction. To test for a change in power, three replications were made of each design point instead of two.

The formula used for power determination is provided by Montgomery in his text, Design and Analysis of Experiments

(28:101).

$$\Phi^2 = \frac{n D^2}{2 a \sigma^2}$$

where Φ = the dependent variable on the Operating Characteristic Curve
n = number of replications
D = the magnitude of the difference to be detected
a = the number of levels for the treatment (factor) variable
σ = the variance of the resulting treatment means

Although only two replications were accomplished for each combination of factor levels for C-max (three for C-min), each level of every factor effectively had 16 replications (24 for C-min). Using this value for the number of replications, the ANOVA Mean Square Error as an estimate of variance, and trying to detect a difference of at least one in the mean of C-max (or C-min), examination of Operating Characteristic curves for fixed effects model (28:515) yielded a power of the experiment of approximately 85% (greater than 99% for C-min). The calculations used to determine these values can be seen in Appendix D.

Summary

This chapter has presented the results of the experimental effort to determine C-max and C-min. The survey used to determine the control capability of a single controller showed that the 'average' controller could simultaneously control 4.61 flights of interceptor aircraft in a C-max environment and 3.40 flights in a C-min

environment. These estimates were based on expert opinion concerning the average controller. The survey results based on perceived individual capabilities resulted in significantly higher values for both figures.

Using the individual control capabilities as an average to be met by the overall air defense system, the experimental design consisted of four factors that were each varied between two levels. This setup constituted a 2^4 factorial design and therefore required 16 different combinations of the levels of the factors to be run for each experiment. Due to computer run time restrictions, only two replications of each design point were performed for the C-max experiment. The C-min experiment was run on another computer system, and three replications of each design point were completed.

The experimental results indicate that the current method used by USAF Studies and Analysis to determine C-max and C-min is appropriate at least in the scenario modeled in this effort. It should be noted, however, that the attack scenario does tend to decrease the value of C-max or C-min if the attack is not uniform throughout the theater. Additionally, the scenario presented in this effort is limited in that it does not include any communications or radar jamming by the hostile forces.

VI. Conclusions and Recommendations

Summary

The purpose of this research was to develop a method to determine two variables, C-max and C-min. These variables represent the maximum number of interceptors that can be controlled by a tactical air defense system. Although both variables represent maximum number of controlled interceptors, C-max refers to interceptor aircraft with internal radars capable of detecting a one square meter target at a range greater than 50 miles, and C-min refers to an interceptor with a radar range of less than 50 miles against the same target. These numbers are used by Air Force Studies and Analysis as input variables to a larger theater combat simulation model, TAC ALLOCATOR.

Although several past research efforts have examined the air defense environment, none have examined it from the viewpoint of the air weapons controller who is responsible for providing the intercept control to the air defense interceptor aircraft. Because of the many different factors that could affect the maximum control capacity of the theater air defense system and the stochastic nature of the arrival and positioning of the hostile aircraft, computer simulation was chosen as the methodology for conducting this research.

The theater air defense system is made up of several different types and numbers of different radar control

systems. Each radar system may be manned by one or more controllers. The sum of these individual controllers' capabilities determine the maximum number of interceptors that can be controlled at any time throughout the theater. Because there are multiple controllers, each having his/her own capabilities, it has been assumed that the theater system may be modeled as being made up of several "average" controllers who have approximately the same control capacity. A survey was used to determine this "average" control capacity under "ideal" circumstances (i.e. no radar or communications jamming).

Using data generated from the results of the individual control survey as well as "generic" specification data for the radar, interceptor and hostile aircraft, and the interceptor missiles, the simulation model was developed and run to determine C-max and C-min. The model was run while varying the following four variables: 1) AWACS availability (yes/no), 2) ground radar type (407L/MCE), 3) number of controllers dedicated to air defense at each radar (1/2), and 4) hostile aircraft attack distribution (uniform/concentrated along one axis).

The results of the simulation runs indicate that Air Force Studies and Analysis' current method for determining C-max and C-min (i.e. multiplying an average control capability by the number of controllers available) is reasonably accurate under the "ideal" conditions of the

simulation. The only discrepancies noted between this method and the simulation results occurred when the hostile aircraft did not penetrate the friendly air defense zone uniformly, but rather concentrated their 'attack' along a single axis. In this 'concentrated attack', C-max and C-min were reached earlier than the simple multiplication would have indicated. This phenomenon is most likely due to an 'area saturation' of the air defense system.

Recommendations for Further Research

Because this was an initial attempt to examine the workings of a theater tactical air defense system, several simplifying assumptions were made in order to complete a working model within the time limits imposed on a thesis effort. Although justified at the time of model development, some assumptions need to be relaxed in order to more accurately portray 'the real world'. When these assumptions are relaxed, the author is not sure that the experimental results would still correspond to the results obtained from the current method for determination of C-max and C-min.

The first assumption that needs to be relaxed is the uniform radar detection range around the radar sites. Terrain features need to be considered which may decrease the detection range along certain azimuths relative to the radar. In addition to the changes in initial detection ranges, it must also be realized that the routing of a

penetrating hostile aircraft may take it outside of detection range after initial detection. While the terrain features may cause an initial detection delay, the moving in and out of radar detection may also cause an increase in controller workload and thereby decrease C-max or C-min.

Another assumption that may cause an even greater effect on C-max and C-min is the assumption concerning the lack of jamming in the scenario. Whether the jamming takes the form of jamming against the radar platforms themselves or the form of jamming the communications links between the interceptor pilots and the weapons controllers, there is probably a very definite effect on C-max and C-min.

Jamming against the radar would cause a delay in detection and would affect the tracking of the hostile aircraft. The delay in radar detection could be modeled in a manner similar to the terrain caused radar detection delays. The effect of the jamming on the tracking would perhaps be more significant by causing the weapons controller to make errors in the intercept calculations. As errors are made, the controller must recompute the intercept calculations as new information becomes available. If enough errors are made, the intercept may be missed totally. Even if the intercept is not missed, the additional calculations required increase the controller workload and thereby probably reduce C-max and C-min.

Communications jamming also tends to induce errors in the intercept process. These errors are the result of the

delay in getting the proper intercept information to the interceptor pilot. Because the interceptor may start or continue on an improper heading, the intercept problem must be recomputed, and the new directions may or may not be received by the interceptor in a timely manner. The overall effect of the errors caused by communications jamming may be considered in a similar manner to the tracking errors caused by radar jamming.

Another assumption that needs to be relaxed is the passive nature of the hostile aircraft. In the current model, the hostile aircraft do not have any offensive capability against the interceptor aircraft. In reality, the hostile aircraft would either have some sort of offensive capability or would be escorted by aircraft that do. Rather than merely directing the interceptor against the hostile aircraft, the controller would also have to be aware of any offensive moves made by the hostile aircraft that would tend to endanger the interceptor. The possibility of a "dogfight" or even a rescue operation for an interceptor that has been shot down greatly increase the controllers workload.

Changes to the simulation model presented in this thesis need not be overly drastic in order to relax the assumptions mentioned above. The basic framework is already in place, all that should need to be accomplished is the addition of several more subroutines to the simulation code.

The errors induced through jamming can probably be modeled as delays in the system. It will be necessary to keep track of the errors as well as the information that describe the correct state of the system at any point in time. Additionally, when these errors are present, some means of reducing the control capability of the controller must be present to take into account the increased workload on the controller caused by these errors.

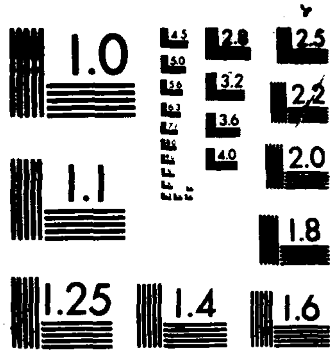
The addition of offensive capability to the penetrating hostile aircraft can be added by providing some means during the actual engagement process to check for the hostile shooting the interceptor. This should require nothing more than reading some initial data concerning enemy weapons and an additional check against some probability of success for the weapons employment during the engagement. Again, some mechanism for decreasing the controller workload capacity must be present if the interceptor is damaged or a rescue attempt is required.

If one recommendation for further research is to be made, it would be to take the simulation model as it now stands, modify it to match the relaxed assumptions noted above and again test the response of C-max and C-min under the new set of conditions. If this were accomplished and time remained for additional research, other factors such as the introduction of systems such as JTIDS (Joint Tactical Information Distribution System) could be included in the model, and their effect on C-max and C-min measured.

Conclusions

Under ideal conditions, C-max and C-min can be predicted with a very high degree of confidence by merely multiplying the average weapons controller maximum control capability and by the number of weapons controllers that will be dedicated to air defense in the tactical theater. The only situation that causes this method to be in error is a non-uniform attack distribution by the hostile forces. If the attack is concentrated in some area, area saturation effects cause a decrease in the observed values of C-max and C-min. The extensive simulation model presented in this thesis confirms this result, but the model should be modified to include such factors as radar detection delays caused by terrain features, radar and communications jamming, and offensive air-to-air capability of the attacking hostile aircraft. Without this further research, the current effort should be treated as a fixed effects model and its results applied only under conditions that match those presented in the model.

AD-A185 268 DETERMINING THE MAXIMUM NUMBER OF RADAR CONTROLLED 2/2
INTERCEPTOR AIRCRAFT B..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. D W CLEMENTS
UNCLASSIFIED JUN 87 AFIT/GST/ENS/87M-5 F/G 17/9 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Appendix A. Research Survey

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-6583

REPLY TO ATTN OF: AFIT/ENS 18 Feb 87

SUBJECT: Research Questionnaire (USAF SCN 87-18, expires 1 May 87)

TO: Air Weapons Controllers

1. Please take the time to complete the attached questionnaire and return it in the attached envelope within five working days.

2. This questionnaire is part of a research effort that is sponsored by the Air Force Center for Studies and Analysis, staffed through HQ TAC, and approved by TAC/DO. The purpose of this effort is to determine the maximum number of interceptors that can be controlled in a tactical air defense environment. Based on the survey results, an "average" controller's capability will be determined and inserted into a theater level air defense air combat simulation model.

3. As a 17XX myself, I can see direct benefits from examining the defensive air battle from the Air Weapons Controller's viewpoint. The results of this study should provide planners with analytic data concerning the capabilities and saturation limits of the air defense command and control system.

4. Your participation in this study is voluntary. There will be no attempt to correlate individuals with their answers, so please respond candidly.

5. Any questions concerning this questionnaire or the overall research effort should be directed to Captain Don Clements, AFIT/ENA, Wright-Patterson AFB, OH 45433-6583, AUTOVON 785-5533.

6. Thank you for your help.

Donald W. Clements

DONALD W. CLEMENTS
Student, Strategic and Tactical Sciences
Air Force Institute of Technology
School of Engineering

2 Atch
1. Questionnaire
2. Envelope

AIR WEAPONS CONTROLLER CAPABILITIES STUDY
(USAF SCN 87-18, Expires 1 May 1987)

*************************** SECTION 1 **************************
**************** QUESTIONS 1 - 5. BACKGROUND ****************

1. Current Control System.
   a. AWACS
   b. 407L
   c. FACP

2. Current Qualification(s). (If staff, indicate current operational qualifications.)
   a. WD/WC
   b. SD/WAO/SENIOR CONTROLLER
   c. INSTRUCTOR WD/WC
   d. INSTRUCTOR SD/WAO
   e. INSTRUCTOR MCC/BD
   f. STAN/EVAL WD/WC
   g. STAN/EVAL SD/WAO
   h. STAN/EVAL MCC/BD

3. LENGTH OF CURRENT QUALIFICATION. (Total time since first becoming qualified in current position, in months.)
   a. WD/WC -- __________.
   b. SD/WAO/SC -- __________.
   c. MCC/BD -- __________.
   d. INSTRUCTOR WD/WC -- __________.
   e. INSTRUCTOR SD/WAO -- __________.
   f. INSTRUCTOR MCC/BD -- __________.
   g. STAN/EVAL WD/WC -- __________.
   h. STAN/EVAL SD/WAO -- __________.
   i. STAN/EVAL MCC/BD -- __________.

4. TOTAL LENGTH OF 17XX QUALIFICATION. (Total time in 17XX career field.)
   a. Less than 2 years.
   b. 2 but less than 5 years.
   c. 5 but less than 8 years.
   d. 8 but less than 10 years.
   e. More than 10 years.

5. OTHER SYSTEMS QUALIFICATIONS. (Do not include your current weapons system. Please indicate total time in system in months.)
   a. AWACS __________.
   b. 407L __________.
   c. SAGE/BUICK __________.
   d. ROCC __________.
   e. FACP __________.
   f. OTHER __________.

*************************** SECTION 2 ***************************
*********** QUESTIONS 6 - 16. PERSONAL CAPABILITY ***********

The following questions ask for your assessment of your own personal ability. Consider your responses carefully. Please try to provide an accurate assessment of what you think you are actually capable of doing. Once again, absolutely no attempt will be made to correlate responses with individuals providing the response. If you are are not currently in a position which requires an active control qualification, skip questions 6 -16, and go to question 17.

When answering these questions, imagine you are providing intercept control in a tactical air defense situation. Control is being provided to only the flight leads. Interceptor flights are assigned to specific CAPs, and specific areas of responsibility are assigned.

**** SELECT ONLY ONE RESPONSE ****

SITUATION: YOU ARE PROVIDING CLOSE CONTROL. ALL INTERCEPTORS ARE ON ONE FREQUENCY. THERE IS NO COMMUNICATIONS OR RADAR JAMMING.

6. What is the MAXIMUM number of flights that you could expect to be able to give control and still maintain situation awareness?

a. 1	f. 6
b. 2	g. 7
c. 3	h. 8
d. 4	i. 9
e. 5	j. 10 or more

7. If all interceptors had 'look-down, shoot-down' radars with ranges of 50NM or greater, your control capability (CLOSE CONTROL) would:
   a. remain the same as in QUESTION 6.
   b. increase by 1 - 2 flights
   c. increase by 3 flights or more
   d. decrease by 1 - 2 flights
   e. decrease by 3 flights or more.

8. If all interceptors have 'minimal' radars with ranges less than 50NM, your control capability (CLOSE CONTROL) would:
   a. remain the same as in QUESTION 6.
   b. increase by 1 - 2 flights
   c. increase by 3 flights or more
   d. decrease by 1 - 2 flights
   e. decrease by 3 flights or more.

SITUATION: YOU ARE PROVIDING TACTICAL CONTROL. ALL INTERCEPTORS ARE ON ONE FREQUENCY. THERE IS NO COMMUNICATIONS OR RADAR JAMMING.

9. What is the MAXIMUM number of flights that you could expect to be able to give control and still maintain situation awareness?

a. 1	f. 6
b. 2	g. 7
c. 3	h. 8
d. 4	i. 9
e. 5	j.10 or more

10. If all interceptors had "look-down, shoot-down" radars with ranges of 50NM or greater, your control capability (TACTICAL CONTROL) would:

a. remain the same as in QUESTION 9.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

11. If all interceptors have "minimal" radars with ranges less than 50NM, your control capability (TACTICAL CONTROL) would:

a. remain the same as in QUESTION 9.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

****

SITUATION: YOU ARE PROVIDING BROADCAST CONTROL. ALL INTERCEPTORS ARE ON ONE FREQUENCY. THERE IS NO COMMUNICATIONS OR RADAR JAMMING.

12. What is the MAXIMUM number of flights that you could expect to be able to give control and still maintain situation awareness?

a. 1	f. 6
b. 2	g. 7
c. 3	h. 8
d. 4	i. 9
e. 5	j.10 or more

13. If all interceptors had "look-down, shoot-down" radars with ranges of 50NM or greater, your control capability (BROADCAST CONTROL) would:

a. remain the same as in QUESTION 12.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

14. If all interceptors have 'minimal' radars with ranges less than 50NM, your control capability (BROADCAST CONTROL) would:

a. remain the same as in QUESTION 12.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

*********** ********** **********

15. In any of the above situations, if you were provided another radio frequency to control the interceptors, your control capability would:

a. remain the same
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

16. How would you rate your capabilities compared with other controllers given the same set of circumstances?

a. about the same
b. 1 - 2 flights better than the 'average' controller
c. more than 3 flights better than the 'average'
d. 1 - 2 flights less than the 'average'
e. less than 3 flights from the 'average'

Questions 17 - 26 are applicable only to INSTRUCTORS, STAN/EVAL, and those whose crew responsibility is direct management of WD's or WC's (i.e. SC's, SD's, WAO's, MCC's, and BD's). If you do not currently hold one of these qualifications, you are finished. THANK YOU for your help with this study .

****** QUESTIONS 17 - 26. OTHER CONTROLLER'S CAPABILITIES ******

When answering the following questions, consider what you believe is the capabilities of the 'average' controller, not your own personal capabilities. Once again, control is being provided to flight leads only in a tactical air defense situation. Interceptor flights are assigned to specific CAPs, and specific areas of responsibility are assigned.

SITUATION: THE CONTROLLER IS PROVIDING CLOSE CONTROL. ALL INTERCEPTORS ARE ON ONE FREQUENCY. THERE IS NO COMMUNICATIONS OR RADAR JAMMING.

17. What is the MAXIMUM number of flights that the 'average' controller could be expected to be able to control and still maintain situation awareness?

a. 1	f. 6
b. 2	g. 7
c. 3	h. 8
d. 4	i. 9
e. 5	j.10 or more

18. If all interceptors had 'look-down, shoot-down' radars with ranges of 50NM or greater, control capability (CLOSE CONTROL) would:

a. remain the same as in QUESTION 17.
b. increase by 1 - 2 flights
c. increase by greater than 3 flights
d. decrease by 1 - 2 flights
e. decrease by greater than 3 flights.

19. If all interceptors have 'minimal' radars with ranges less than 50NM, control capability (CLOSE CONTROL) would:

a. remain the same as in QUESTION 17.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

SITUATION: THE CONTROLLER IS PROVIDING TACTICAL CONTROL. ALL INTERCEPTORS ARE ON ONE FREQUENCY. THERE IS NO COMMUNICATIONS OR RADAR JAMMING.

20. What is the MAXIMUM number of flights that the 'average' controller could be expected to be able to control and still maintain situation awareness?

a. 1	f. 6
b. 2	g. 7
c. 3	h. 8
d. 4	i. 9
e. 5	j. 10 or more

21. If all interceptors had 'look-down, shoot-down' radars with ranges of 50NM or greater, control capability (TACTICAL CONTROL) would:

a. remain the same as in QUESTION 20.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

22. If all interceptors have 'minimal' radars with ranges less than 50NM, control capability (TACTICAL CONTROL) would:

a. remain the same as in QUESTION 20.
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

****

SITUATION: THE CONTROLLER IS PROVIDING BROADCAST CONTROL. ALL INTERCEPTORS ARE ON ONE FREQUENCY. THERE IS NO COMMUNICATIONS OR RADAR JAMMING.

23. What is the MAXIMUM number of flights that the 'average' controller could be expected to be able to control and still maintain situation awareness?

a. 1	f. 6
b. 2	g. 7
c. 3	h. 8
d. 4	i. 9
e. 5	j. 10 or more

24. If all interceptors had 'look-down, shoot-down' radars with ranges of 50NM or greater, control capability (BROADCAST CONTROL) would:

a. remain the same as in QUESTION 23
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

25. If all interceptors have 'minimal' radars with ranges less than 50NM, control capability (BROADCAST CONTROL) would:

a. remain the same as in QUESTION 23
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

********** ********** **********

26. In any of the above situations, if the controller was provided another radio frequency to control the interceptors, 'average' control capability would:

a. remain the same
b. increase by 1 - 2 flights
c. increase by 3 flights or more
d. decrease by 1 - 2 flights
e. decrease by 3 flights or more.

Thank you for your cooperation. If you have any additional comments, please feel free to write them here. If you think I should discuss this with you further, please provide your name and a duty phone and I will get back to you. Once again, THANKS.

Appendix B. Analysis of Survey Data

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
1	AWACS	24	0	0	24	0	0	0	0	0	6.5	45	3
2	AWACS	13	0	0	13	0	0	0	0	0	3.5	0	4
3	AWACS	62	30	0	36	0	0	0	0	0	6.5	0	1
4	AWACS	48	24	0	0	24	0	0	0	0	3.5	0	3
5	407L	2	0	0	0	0	0	0	0	0	2.0	0	4
6	AWACS	0	0	0	0	0	0	0	0	0	6.5	58	4
7	AWACS	6	0	0	0	0	0	0	0	0	1.0	0	3
8	AWACS	23	0	0	0	0	0	0	0	0	6.5	48	4
9	AWACS	24	0	0	18	0	0	0	0	0	6.5	41	8
10	407L	1	0	0	0	0	0	0	0	0	9.5	98	4
11	407L	72	48	0	60	3	0	3	3	3	6.5	12	4
12	407L	43	0	0	31	0	0	0	0	0	3.5	0	5
13	FACP	48	0	0	18	0	0	0	0	0	6.5	0	3
14	407L	72	0	0	0	0	0	0	0	0	9.5	63	10
15	FACP	2	0	0	0	0	0	0	0	0	1.0	0	4

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
1	0.0	-1.5	4	1.5	-1.5	6	0.0	0.0	0.0	0.0	2	1.5	0.0
2	1.5	0.0	4	1.5	0.0	10	0.0	0.0	0.0	1.5	2	1.5	-1.5
3	0.0	0.0	1	0.0	0.0	1	0.0	0.0	0.0	3.0	1	0.0	0.0
4	1.5	0.0	3	1.5	0.0	7	0.0	0.0	0.0	0.0	3	0.0	0.0
5	1.5	0.0	8	1.5	0.0	10	0.0	0.0	-1.5	0.0	0	0.0	0.0
6	0.0	0.0	8	1.5	0.0	5	0.0	0.0	-1.5	1.5	0	0.0	0.0
7	1.5	0.0	4	0.0	-1.5	3	1.5	0.0	0.0	1.5	0	0.0	0.0
8	1.5	0.0	6	3.0	0.0	10	0.0	0.0	0.0	0.0	0	0.0	0.0
9	1.5	0.0	10	0.0	0.0	8	0.0	0.0	0.0	3.0	4	0.0	-1.5
10	3.0	-1.5	10	1.5	0.0	10	3.0	0.0	0.0	3.0	0	0.0	0.0
11	1.5	0.0	8	0.0	0.0	10	0.0	0.0	-1.5	1.5	2	0.0	0.0
12	1.5	0.0	7	1.5	0.0	7	1.5	0.0	0.0	1.5	4	1.5	-1.5
13	1.5	-1.5	4	1.5	-1.5	5	1.5	-1.5	-1.5	1.5	2	1.5	-1.5
14	3.0	0.0	10	3.0	0.0	10	0.0	0.0	-1.5	1.5	6	0.0	-1.5
15	1.5	-1.5	5	1.5	-1.5	8	1.5	0.0	3.0	-1.5	0	0.0	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
1	3	0.0	-1.5	5	0.0	0.0	0.0	0.0	5.5	2.5
2	2	1.5	-1.5	7	0.0	0.0	-1.5	0.0	5.5	4.0
3	1	0.0	0.0	1	0.0	0.0	0.0	0.0	1.0	1.0
4	3	0.0	0.0	7	0.0	0.0	0.0	0.0	4.5	3.0
5	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	9.5	8.0
6	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	9.5	8.0
7	0	0.0	0.0	0	0.0	0.0	0.0	0.0	4.0	2.5
8	0	0.0	0.0	0	0.0	0.0	0.0	0.0	9.0	6.0
9	4	0.0	0.0	4	0.0	-1.5	0.0	0.0	10.0	10.0
10	0	0.0	0.0	0	0.0	0.0	0.0	0.0	11.5	10.0
11	4	3.0	-1.5	10	0.0	0.0	0.0	-1.5	8.0	8.0
12	5	1.5	0.0	6	1.5	0.0	0.0	0.0	8.5	7.0
13	3	1.5	-1.5	4	1.5	-1.5	-1.5	-1.5	5.5	2.5
14	7	1.5	-1.5	5	0.0	-1.5	-1.5	-1.5	13.0	10.0
15	0	0.0	0.0	0	0.0	0.0	0.0	3.0	6.5	3.5

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
16	407L	1	0	0	0	0	0	0	0	0	1.0	0	3
17	FACP	6	0	0	0	0	0	0	0	0	1.0	0	4
18	FACP	9	2	0	0	0	0	0	0	0	1.0	0	3
19	FACP	96	0	0	0	0	0	0	0	0	9.5	48	4
20	FACP	7	0	0	0	0	0	0	0	0	1.0	28	6
21	407L	28	18	0	28	18	0	18	18	0	6.5	91	4
22	407L	0	0	20	0	0	0	0	0	0	10.0	108	4
23	AWACS	24	0	0	9	0	0	0	0	0	3.5	0	5
24	407L	14	0	0	0	0	0	0	0	0	9.5	0	2
25	FACP	12	0	0	2	0	0	0	0	0	1.5	0	3
26	AWACS	48	48	0	48	48	0	0	0	0	9.5	60	3
27	AWACS	5	0	0	0	0	0	0	0	0	1.0	0	4
28	AWACS	0	0	39	0	0	0	0	0	0	10.0	36	2
29	AWACS	0	0	50	0	0	42	0	0	0	10.0	170	5
30	AWACS	9	0	0	0	0	0	0	0	0	1.0	0	3

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
16	1.5	0.0	3	1.5	1.5	3	1.5	0.0	0.0	0.0	0	0.0	0.0
17	0.0	0.0	6	0.0	0.0	4	0.0	0.0	0.0	0.0	0	0.0	0.0
18	0.0	-1.5	5	0.0	1.5	7	0.0	-1.5	3.0	1.5	4	0.0	-1.5
19	0.0	0.0	10	0.0	0.0	10	0.0	0.0	-1.5	3.0	4	0.0	0.0
20	3.0	0.0	9	1.5	0.0	10	3.0	-1.5	3.0	3.0	0	0.0	0.0
21	1.5	0.0	8	1.5	0.0	10	0.0	0.0	0.0	1.5	2	1.5	0.0
22	0.0	0.0	4	0.0	0.0	6	0.0	0.0	1.5	1.6	2	0.0	0.0
23	3.0	0.0	8	1.5	-1.5	10	1.5	-3.0	-1.5	1.5	5	1.5	0.0
24	0.0	0.0	4	1.5	0.0	6	1.5	0.0	0.0	0.0	0	0.0	0.0
25	1.5	0.0	5	0.0	0.0	10	0.0	0.0	1.5	0.0	0	1.5	-1.5
26	1.5	0.0	5	0.0	-1.5	10	3.0	3.0	-1.5	3.0	2	0.0	-1.5
27	1.5	-1.5	5	1.5	-1.5	7	1.5	0.0	-1.5	0.0	0	0.0	0.0
28	0.0	0.0	2	0.0	0.0	2	0.0	0.0	0.0	0.0	2	0.0	0.0
29	1.5	0.0	8	0.0	0.0	8	0.0	0.0	0.0	1.5	3	0.0	-1.5
30	1.5	0.0	4	1.5	0.0	6	1.5	0.0	0.0	0.0	0	0.0	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
16	0	0.0	0.0	0	0.0	0.0	0.0	0.0	4.5	4.5
17	0	0.0	0.0	0	0.0	0.0	0.0	0.0	6.0	6.0
18	5	1.5	-1.5	8	0.0	0.0	1.5	3.0	5.0	6.5
19	6	0.0	0.0	7	0.0	0.0	-1.5	-1.5	10.0	10.0
20	0	0.0	0.0	0	0.0	0.0	0.0	3.0	10.5	9.0
21	4	3.0	0.0	4	3.0	0.0	0.0	0.0	9.5	8.0
22	2	0.0	0.0	4	0.0	1.5	0.0	1.5	4.0	4.0
23	8	3.0	-1.5	10	3.0	-3.0	1.5	-1.5	9.5	6.5
24	0	0.0	0.0	0	0.0	0.0	0.0	0.0	5.5	4.0
25	4	0.0	0.0	8	0.0	0.0	0.0	1.5	5.0	5.0
26	2	0.0	0.0	5	0.0	0.0	1.5	-1.5	5.0	3.5
27	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	6.5	3.5
28	2	0.0	0.0	2	0.0	0.0	1.5	0.0	2.0	2.0
29	3	0.0	-1.5	4	0.0	-1.5	0.0	0.0	8.0	8.0
30	0	0.0	0.0	0	0.0	0.0	0.0	0.0	5.5	4.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
31	AWACS	24	24	0	18	18	0	0	0	0	9.5	36	4
32	AWACS	54	36	0	0	0	0	0	0	0	9.5	54	3
33	AWACS	30	0	0	9	0	0	0	0	0	3.5	0	4
34	AWACS	0	0	36	0	0	0	0	0	0	10.0	108	3
35	AWACS	16	0	0	0	0	0	0	0	0	1.5	0	4
36	AWACS	18	0	0	0	0	0	0	0	0	6.5	58	3
37	AWACS	42	0	0	0	0	0	0	0	0	4.0	0	2
38	AWACS	49	16	0	31	0	0	0	0	0	6.5	0	4
39	AWACS	31	0	0	0	0	0	0	0	0	3.5	0	6
40	AWACS	5	0	0	0	0	0	0	0	0	1.0	0	3
41	AWACS	17	0	0	0	0	0	0	0	0	3.5	3	4
42	AWACS	4	0	0	0	0	0	0	0	0	1.0	0	5
43	407L	13	0	0	0	0	0	0	0	0	2.0	0	1
44	407L	36	0	0	6	0	0	0	0	0	4.0	0	5
45	407L	11	0	0	0	0	0	0	0	0	1.5	0	2

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
31	0.0	-1.5	4	0.0	-1.5	6	0.0	-1.5	1.5	1.5	2	0.0	-1.5
32	1.5	0.0	4	3.0	0.0	10	0.0	0.0	1.5	1.5	3	1.5	0.0
33	1.5	0.0	6	1.5	0.0	5	0.0	0.0	-1.5	1.5	4	1.5	0.0
34	1.5	0.0	3	1.5	0.0	10	0.0	0.0	0.0	1.5	2	1.5	0.0
35	1.5	0.0	6	1.5	0.0	10	0.0	0.0	-1.5	0.0	0	0.0	0.0
36	1.5	-1.5	5	0.0	0.0	7	3.0	0.0	0.0	0.0	0	0.0	0.0
37	0.0	0.0	3	1.5	0.0	2	0.0	-1.5	0.0	-1.5	0	0.0	0.0
38	1.5	-1.5	6	1.5	-1.5	8	1.5	-1.5	-1.5	1.5	3	1.5	-1.5
39	3.0	0.0	8	1.5	0.0	8	0.0	0.0	0.0	1.5	0	0.0	0.0
40	1.5	-1.5	3	0.0	0.0	4	0.0	0.0	0.0	-1.5	0	0.0	0.0
41	1.5	0.0	6	3.0	-1.5	10	0.0	0.0	0.0	0.0	0	0.0	0.0
42	1.5	-1.5	7	1.5	-1.5	9	1.5	-1.5	1.5	0.0	0	0.0	0.0
43	1.5	0.0	2	1.5	0.0	4	0.0	0.0	-1.5	-1.5	0	0.0	0.0
44	3.0	0.0	8	0.0	0.0	10	3.0	0.0	0.0	3.0	4	1.5	0.0
45	1.5	0.0	2	1.5	0.0	4	0.0	0.0	0.0	0.0	0	0.0	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
31	2	0.0	-1.5	4	0.0	-1.5	1.5	1.5	4.0	2.5
32	4	0.0	-1.5	6	1.5	0.0	0.0	1.5	7.0	4.0
33	6	1.5	0.0	9	1.5	0.0	0.0	-1.5	7.5	6.0
34	3	1.5	-1.5	10	0.0	0.0	0.0	0.0	4.5	3.0
35	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	7.5	6.0
36	0	0.0	0.0	0	0.0	0.0	0.0	0.0	5.0	5.0
37	0	0.0	0.0	0	0.0	0.0	0.0	0.0	4.5	3.0
38	4	1.5	-1.5	5	1.5	-1.5	-1.5	-1.5	7.5	4.5
39	0	0.0	0.0	0	0.0	0.0	0.0	0.0	9.5	8.0
40	0	0.0	0.0	0	0.0	0.0	0.0	0.0	3.0	3.0
41	0	0.0	0.0	0	0.0	0.0	0.0	0.0	9.0	4.5
42	0	0.0	0.0	0	0.0	0.0	0.0	1.5	8.5	5.5
43	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	3.5	2.0
44	6	1.5	0.0	8	3.0	0.0	0.0	0.0	8.0	8.0
45	0	0.0	0.0	0	0.0	0.0	0.0	0.0	3.5	2.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
46	AWACS	36	0	0	24	0	0	0	0	0	4.0	0	3
47	AWACS	0	0	86	0	0	0	0	0	0	10.0	34	2
48	AWACS	39	0	0	20	0	0	1	0	0	4.0	0	5
49	AWACS	24	0	0	3	0	0	0	0	0	3.5	4	3
50	AWACS	48	12	0	36	0	0	18	0	0	4.5	0	4
51	AWACS	18	10	0	0	0	0	0	0	0	10.0	96	5
52	AWACS	47	23	0	0	0	0	0	0	0	4.5	0	4
53	AWACS	2	0	0	0	0	0	0	0	0	3.5	32	3
54	AWACS	36	0	0	12	0	0	0	0	0	4.0	3	4
55	AWACS	8	0	0	0	0	0	0	0	0	2.0	0	4
56	AWACS	24	0	0	12	0	0	0	0	0	3.5	0	3
57	AWACS	24	0	0	6	0	0	0	0	0	3.5	0	4
58	AWACS	12	0	0	0	0	0	0	0	0	9.5	96	5
59	AWACS	12	0	0	0	0	0	0	0	0	1.5	0	3
60	AWACS	48	30	0	20	20	0	0	0	0	9.5	36	6

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
46	0.0	0.0	3	1.5	0.0	10	0.0	0.0	-1.5	0.0	2	1.5	0.0
47	1.5	1.5	4	0.0	0.0	5	1.5	0.0	0.0	1.5	2	0.0	0.0
48	0.0	0.0	5	0.0	0.0	5	0.0	0.0	-1.5	1.5	2	0.0	0.0
49	1.5	0.0	5	1.5	0.0	7	1.5	0.0	0.0	0.0	3	1.5	0.0
50	1.5	0.0	6	0.0	-1.5	10	0.0	0.0	0.0	3.0	2	0.0	0.0
51	3.0	1.5	5	3.0	1.5	10	3.0	1.5	1.5	3.0	2	1.5	1.5
52	1.5	0.0	4	0.0	0.0	10	0.0	0.0	0.0	0.0	4	1.5	0.0
53	1.5	0.0	4	0.0	-1.5	5	0.0	0.0	0.0	0.0	0	0.0	0.0
54	1.5	0.0	6	1.5	0.0	8	0.0	0.0	1.5	1.5	4	1.5	-1.5
55	1.5	0.0	6	0.0	0.0	8	0.0	0.0	1.5	0.0	0	0.0	0.0
56	0.0	0.0	4	0.0	0.0	10	3.0	3.0	0.0	0.0	2	0.0	0.0
57	1.5	0.0	6	1.5	0.0	10	0.0	0.0	-1.5	1.5	3	1.5	-1.5
58	0.0	-1.5	5	0.0	-1.5	5	0.0	-1.5	0.0	3.0	0	0.0	0.0
59	0.0	-1.5	4	1.5	-1.5	8	1.5	0.0	-1.5	0.0	0	0.0	0.0
60	1.5	0.0	7	1.5	0.0	9	1.5	0.0	1.5	1.5	3	1.5	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
46	3	1.5	0.0	7	1.5	0.0	-1.5	-1.5	4.5	3.0
47	3	0.0	0.0	3	0.0	0.0	0.0	0.0	4.0	4.0
48	3	0.0	0.0	3	0.0	0.0	-1.5	-1.5	5.0	5.0
49	5	1.5	0.0	7	1.5	0.0	0.0	0.0	6.5	5.0
50	4	1.5	-1.5	6	1.5	-1.5	0.0	0.0	6.0	4.5
51	3	1.5	1.5	4	1.5	1.5	0.0	1.5	8.0	6.5
52	4	0.0	0.0	10	0.0	0.0	0.0	0.0	4.0	4.0
53	0	0.0	0.0	0	0.0	0.0	0.0	0.0	4.0	2.5
54	5	0.0	-1.5	7	0.0	-1.5	0.0	1.5	7.5	6.0
55	0	0.0	0.0	0	0.0	0.0	0.0	1.5	6.0	6.0
56	3	0.0	0.0	10	0.0	0.0	0.0	0.0	4.0	4.0
57	4	1.5	-1.5	7	0.0	0.0	-1.5	-1.5	7.5	6.0
58	0	0.0	0.0	0	0.0	0.0	0.0	0.0	5.0	3.5
59	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	5.5	2.5
60	3	1.5	0.0	7	0.0	0.0	1.5	1.5	8.5	7.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
61	AWACS	11	0	0	0	0	0	0	0	0	6.5	66	6
62	AWACS	12	0	0	0	0	0	0	0	0	6.5	48	2
63	AWACS	11	0	0	4	0	0	0	0	0	1.5	0	4
64	FACP	76	0	0	62	0	0	40	0	0	7.0	76	7
65	AWACS	19	0	0	0	0	0	0	0	0	1.9	0	3
66	AWACS	0	0	40	0	0	0	0	0	0	10.0	100	0
67	AWACS	24	0	0	6	0	0	0	0	0	3.5	0	5
68	AWACS	30	24	0	0	0	0	0	0	0	6.5	48	3
69	AWACS	12	12	0	0	7	0	0	0	0	3.5	0	3
70	AWACS	27	19	0	0	0	0	0	0	0	3.5	0	6
71	AWACS	47	0	0	37	0	0	0	0	0	6.5	0	4
72	AWACS	30	0	0	0	0	0	0	0	0	3.5	0	1
73	AWACS	36	0	0	30	0	0	24	0	0	3.5	0	4
74	407L	21	0	0	0	0	0	0	0	0	3.5	12	6
75	407L	1	1	1	0	0	0	0	0	0	9.5	96	4

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18
61	1.5	-1.5	8	0.0	0.0	10	0.0	0.0	0.0	1.5	0	0.0
62	1.5	0.0	4	3.0	-1.5	10	3.0	-1.5	0.0	0.0	0	0.0
63	3.0	0.0	5	1.5	0.0	8	1.5	0.0	-1.5	0.0	4	1.5
64	3.0	-3.0	7	1.5	-1.5	10	3.0	0.0	3.0	3.0	4	1.5
65	1.5	-1.5	4	1.5	-1.5	6	3.0	0.0	1.5	1.5	0	0.0
66	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	2	1.5
67	-3.0	-1.5	9	-3.0	0.0	10	3.0	0.0	0.0	3.0	3	1.5
68	1.5	0.0	5	0.0	0.0	7	0.0	0.0	0.0	0.0	3	1.5
69	0.0	0.0	4	0.0	0.0	5	0.0	0.0	0.0	1.5	2	0.0
70	3.0	-3.0	10	3.0	-3.0	10	0.0	0.0	-1.5	1.5	3	0.0
71	1.5	-1.5	6	0.0	-3.0	10	0.0	0.0	1.5	1.5	2	1.5
72	0.0	0.0	2	0.0	0.0	2	0.0	-1.5	-1.5	-1.5	0	0.0
73	1.5	0.0	8	0.0	0.0	10	0.0	0.0	-1.5	1.5	3	1.5
74	-1.5	-1.5	6	0.0	0.0	10	0.0	0.0	-3.0	0.0	0	0.0
75	1.5	0.0	4	1.5	0.0	6	0.0	0.0	-1.5	0.0	2	0.0

OBS	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
61	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	8.0	8.0
62	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	7.0	2.5
63	0.0	4	1.5	0.0	8	3.0	0.0	-1.5	-1.5	6.5	5.0
64	-1.5	5	1.5	-1.5	6	3.0	0.0	1.5	3.0	8.5	5.5
65	0.0	0	0.0	0.0	0	0.0	0.0	0.0	1.5	5.5	2.5
66	0.0	3	0.0	0.0	3	1.5	0.0	0.0	0.0	0.0	0.0
67	0.0	4	1.5	1.5	5	0.0	0.0	0.0	0.0	6.0	9.0
68	0.0	5	0.0	-1.5	5	0.0	0.0	0.0	0.0	5.0	5.0
69	0.0	2	0.0	0.0	2	0.0	0.0	0.0	0.0	4.0	4.0
70	0.0	4	0.0	0.0	5	0.0	0.0	-1.5	-1.5	13.0	7.0
71	-1.5	3	1.5	-1.5	6	0.0	0.0	1.5	1.5	6.0	3.0
72	0.0	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	2.0	2.0
73	0.0	4	0.0	0.0	5	0.0	0.0	-1.5	-1.5	8.0	8.0
74	0.0	0	0.0	0.0	0	0.0	0.0	0.0	-3.0	6.0	6.0
75	-1.5	3	1.5	1.5	4	0.0	0.0	-1.5	-1.5	5.5	4.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
76	AWACS	30	24	0	12	12	0	0	0	0	3.5	0	4
77	AWACS	48	42	0	30	30	0	10	10	0	6.5	33	4
78	AWACS	38	0	0	24	0	0	12	0	0	4.0	0	5
79	AWACS	24	0	0	3	0	0	0	0	0	6.5	33	4
80	AWACS	0	0	30	0	0	22	0	0	0	10.0	132	4
81	AWACS	9	0	0	0	0	0	0	0	0	1.5	0	3
82	AWACS	0	0	19	0	0	10	0	0	0	3.5	0	3
83	AWACS	30	0	0	0	0	0	0	0	0	3.5	1	4
84	AWACS	0	0	18	0	0	0	0	0	0	9.5	78	4
85	AWACS	48	36	0	6	6	0	0	0	0	10.0	48	3
86	AWACS	10	0	0	0	0	0	0	0	0	6.5	12	6
87	AWACS	24	0	0	12	0	0	3	0	0	3.5	0	3
88	AWACS	24	3	0	0	0	0	0	0	0	3.5	0	5
89	AWACS	18	0	0	3	0	0	0	0	0	3.5	4	4
90	AWACS	1	0	0	0	0	0	0	0	0	3.5	36	3

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
76	3.0	0.0	8	0.0	0.0	8	0.0	0.0	0.0	1.5	4	0.0	0.0
77	1.5	0.0	8	0.0	0.0	9	0.0	0.0	0.0	1.5	3	1.5	-1.5
78	1.5	-1.5	8	1.5	-1.5	8	1.5	-1.5	0.0	3.0	2	0.0	-1.5
79	1.5	0.0	6	1.5	0.0	8	1.5	0.0	0.0	1.5	3	1.5	0.0
80	1.5	-1.5	8	0.0	0.0	10	0.0	0.0	0.0	-3.0	3	1.5	-1.5
81	1.5	0.0	4	1.5	0.0	7	1.5	0.0	0.0	0.0	0	0.0	0.0
82	1.5	0.0	4	1.5	0.0	5	1.5	0.0	0.0	0.0	4	1.5	0.0
83	3.0	-1.5	7	0.0	-1.5	7	0.0	-1.5	0.0	1.5	0	0.0	0.0
84	1.5	0.0	6	3.0	0.0	8	3.0	0.0	1.5	3.0	2	0.0	0.0
85	1.5	-1.5	5	1.5	0.0	10	0.0	0.0	0.0	1.5	1	0.0	0.0
86	3.0	-1.5	6	3.0	-1.5	8	3.0	-1.5	-1.5	1.5	0	0.0	0.0
87	1.5	-1.5	4	1.5	0.0	6	1.5	-1.5	0.0	3.0	2	1.5	-1.5
88	3.0	0.0	8	3.0	-3.0	9	3.0	0.0	1.5	1.5	5	1.5	-1.5
89	3.0	0.0	8	3.0	0.0	10	0.0	0.0	3.0	1.5	2	0.0	0.0
90	3.0	-1.5	4	1.5	-1.5	4	1.5	-1.5	0.0	1.5	0	0.0	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
76	7	0.0	0.0	5	0.0	0.0	0.0	0.0	8.0	8.0
77	4	0.0	0.0	5	0.0	0.0	1.5	0.0	8.0	8.0
78	3	0.0	-1.5	3	0.0	-1.5	-1.5	0.0	9.5	6.5
79	4	1.5	0.0	5	1.5	0.0	-1.5	0.0	7.5	6.0
80	8	0.0	0.0	10	0.0	0.0	0.0	0.0	8.0	8.0
81	0	0.0	0.0	0	0.0	0.0	0.0	0.0	5.5	4.0
82	5	1.5	0.0	5	1.5	0.0	1.5	0.0	5.5	4.0
83	0	0.0	0.0	0	0.0	0.0	0.0	0.0	7.0	5.5
84	4	0.0	0.0	4	1.5	0.0	1.5	1.5	9.0	6.0
85	2	1.5	-1.5	10	0.0	0.0	0.0	0.0	6.5	5.0
86	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	9.0	4.5
87	3	1.5	-1.5	4	1.5	-1.5	0.0	0.0	5.5	4.0
88	8	1.5	-1.5	8	1.5	-1.5	1.5	1.5	11.0	5.0
89	5	1.5	0.0	6	0.0	0.0	1.5	3.0	11.0	8.0
90	0	0.0	0.0	0	0.0	0.0	0.0	0.0	5.5	2.5

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6	Q7
91	AWACS	80	72	0	0	0	0	0	0	0	10.0	24	3	0.0
92	AWACS	13	0	0	0	0	0	0	0	0	1.5	0	2	0.0
93	AWACS	24	0	0	1	0	0	0	0	0	3.5	0	6	1.5
94	AWACS	43	0	0	31	0	0	0	0	0	6.5	0	3	1.5
95	AWACS	11	0	0	5	0	0	0	0	0	2.5	0	4	1.5
96	AWACS	0	0	16	0	0	0	0	0	0	15.0	168	2	1.5
97	AWACS	18	3	0	0	0	0	0	0	0	6.5	60	6	0.0
98	AWACS	6	0	0	0	0	0	0	0	0	1.0	3	4	1.5
99	AWACS	24	0	0	5	0	0	0	0	0	3.5	0	3	0.0
100	AWACS	36	0	0	18	0	0	7	0	0	3.5	0	6	3.0
101	AWACS	36	0	0	24	0	0	7	0	0	3.5	0	5	1.5
102	AWACS	30	0	0	19	0	0	0	0	0	3.5	0	4	3.0
103	AWACS	7	0	0	0	0	0	0	0	0	6.5	66	4	0.0
104	AWACS	36	0	0	16	0	0	0	0	0	3.5	0	5	1.5
105	AWACS	0	0	80	0	0	40	0	0	0	10.0	120	4	1.5

OBS	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
91	0.0	4	0.0	0.0	5	0.0	0.0	0.0	1.5	2	0.0	0.0	3
92	0.0	3	0.0	0.0	5	0.0	0.0	0.0	0.0	0	0.0	0.0	0
93	-1.5	6	3.0	0.0	10	0.0	0.0	0.0	-1.5	3	0.0	0.0	3
94	0.0	4	1.5	0.0	10	0.0	0.0	0.0	1.5	2	0.0	0.0	3
95	0.0	6	0.0	0.0	8	0.0	0.0	0.0	1.5	3	1.5	0.0	4
96	0.0	3	1.5	-1.5	10	0.0	0.0	-1.5	-1.5	2	1.5	-1.5	3
97	0.0	6	0.0	0.0	10	3.0	0.0	0.0	3.0	3	1.5	0.0	4
98	0.0	5	1.5	0.0	8	0.0	0.0	-1.5	1.5	0	0.0	0.0	0
99	0.0	4	0.0	0.0	5	0.0	0.0	0.0	0.0	2	1.5	0.0	3
100	0.0	8	1.5	0.0	10	0.0	0.0	1.5	3.0	4	1.5	-1.5	6
101	-1.5	5	1.5	-1.5	7	0.0	0.0	0.0	1.5	3	0.0	0.0	3
102	0.0	5	0.0	-1.5	10	0.0	0.0	0.0	1.5	3	1.5	-1.5	4
103	0.0	4	0.0	0.0	7	0.0	0.0	1.5	1.5	0	0.0	0.0	0
104	-1.5	10	1.5	0.0	10	3.0	0.0	-1.5	1.5	3	0.0	0.0	4
105	0.0	6	0.0	-1.5	8	0.0	0.0	0.0	3.0	2	0.0	-1.5	3

OBS	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
91	0.0	0.0	4	0.0	0.0	0.0	0.0	4.0	4.0
92	0.0	0.0	0	0.0	0.0	0.0	0.0	3.0	3.0
93	3.0	3.0	10	0.0	0.0	0.0	0.0	9.0	6.0
94	0.0	0.0	6	0.0	0.0	0.0	0.0	5.5	4.0
95	0.0	0.0	6	0.0	0.0	0.0	0.0	6.0	6.0
96	0.0	-1.5	10	0.0	0.0	-1.5	-1.5	4.5	1.5
97	1.5	-1.5	5	1.5	0.0	1.5	0.0	6.0	6.0
98	0.0	0.0	0	0.0	0.0	0.0	-1.5	6.5	5.0
99	1.5	0.0	4	1.5	0.0	0.0	0.0	4.0	4.0
100	1.5	-1.5	8	0.0	0.0	0.0	1.5	9.5	8.0
101	0.0	0.0	5	0.0	0.0	0.0	0.0	6.5	3.5
102	0.0	-1.5	8	0.0	0.0	-1.5	0.0	5.0	3.5
103	0.0	0.0	0	0.0	0.0	0.0	1.5	4.0	4.0
104	1.5	0.0	7	1.5	0.0	-1.5	-1.5	11.5	10.0
105	0.0	-1.5	4	0.0	0.0	0.0	0.0	6.0	4.5

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6	Q7
106	407L	8	0	0	0	0	0	0	0	0	3.5	1	1	1.5
107	AWACS	0	0	0	0	0	0	0	1	0	3.5	0	3	1.5
108	AWACS	0	0	36	0	0	12	0	0	0	10.0	84	4	3.0
109	AWACS	36	0	0	18	0	0	0	0	0	3.5	0	5	1.5
110	AWACS	0	0	0	2	0	0	0	0	0	3.5	0	2	1.5
111	AWACS	0	30	0	0	0	0	0	0	0	9.5	43	4	1.5
112	AWACS	12	0	0	0	0	0	0	0	0	1.5	2	5	3.0
113	AWACS	7	0	0	0	0	0	0	0	0	1.5	0	4	1.5
114	AWACS	3	0	0	0	0	0	0	0	0	1.4	0	2	0.0
115	AWACS	0	25	0	35	0	0	0	0	0	6.5	12	4	1.5
116	AWACS	0	6	0	18	0	0	0	0	0	3.5	0	3	1.5
117	AWACS	36	0	0	0	0	0	0	0	0	3.5	0	6	3.0
118	AWACS	0	0	0	0	0	0	0	21	0	9.5	48	4	0.0
119	AWACS	11	0	0	0	0	0	0	0	0	10.0	82	3	0.0
120	AWACS	15	0	0	9	0	0	0	0	0	9.5	48	4	1.5

OBS	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
106	0.0	2	1.5	-1.5	3	1.5	-1.5	-1.5	1.5	0	0.0	0.0	0
107	0.0	3	1.5	0.0	9	-1.5	0.0	0.0	0.0	2	0.0	0.0	2
108	1.5	4	3.0	1.5	4	3.0	0.0	0.0	1.5	3	1.5	-1.5	3
109	0.0	6	1.5	0.0	10	0.0	0.0	0.0	3.0	3	1.5	0.0	3
110	0.0	3	1.5	0.0	5	0.0	0.0	-1.5	1.5	2	0.0	0.0	2
111	0.0	7	3.0	0.0	10	3.0	0.0	0.0	0.0	3	1.5	-1.5	6
112	0.0	8	1.5	-1.5	10	3.0	-1.5	1.5	0.0	0	0.0	0.0	0
113	0.0	8	1.5	0.0	10	1.5	0.0	3.0	1.5	0	0.0	0.0	0
114	0.0	3	0.0	-1.5	4	0.0	-1.5	1.5	0.0	0	0.0	0.0	0
115	0.0	8	1.5	0.0	10	3.0	3.0	-1.5	1.5	2	1.5	0.0	3
116	0.0	5	1.5	0.0	8	3.0	0.0	0.0	3.0	2	1.5	0.0	3
117	0.0	6	3.0	0.0	10	3.0	0.0	-1.5	1.5	0	0.0	0.0	0
118	0.0	8	0.0	0.0	10	3.0	3.0	0.0	3.0	2	0.0	0.0	5
119	0.0	5	1.5	0.0	10	0.0	0.0	0.0	0.0	0	0.0	0.0	0
120	0.0	5	1.5	0.0	6	1.5	0.0	0.0	1.5	3	1.5	0.0	3

OBS	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
106	0.0	0.0	0	0.0	0.0	0.0	-1.5	3.5	0.5
107	1.5	0.0	7	0.0	0.0	0.0	0.0	4.5	3.0
108	1.5	-1.5	4	1.5	0.0	0.0	0.0	7.0	5.5
109	1.5	0.0	6	0.0	0.0	0.0	0.0	7.5	6.0
110	0.0	0.0	3	0.0	0.0	-1.5	-1.5	4.5	3.0
111	1.5	0.0	8	1.5	-1.5	0.0	0.0	10.0	7.0
112	0.0	0.0	0	0.0	0.0	0.0	1.5	9.5	6.5
113	0.0	0.0	0	0.0	0.0	0.0	3.0	9.5	8.0
114	0.0	0.0	0	0.0	0.0	0.0	1.5	3.0	1.5
115	1.5	0.0	7	0.0	0.0	0.0	-1.5	9.5	8.0
116	0.0	0.0	7	0.0	0.0	0.0	0.0	6.5	5.0
117	0.0	0.0	0	0.0	0.0	0.0	-1.5	9.0	6.0
118	0.0	0.0	7	0.0	0.0	0.0	0.0	8.0	8.0
119	0.0	0.0	0	0.0	0.0	0.0	0.0	6.5	5.0
120	1.5	0.0	4	1.5	0.0	0.0	0.0	6.5	5.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
121	AWACS	0	0	0	0	0	15	0	0	0	3.5	0	4
122	AWACS	13	0	0	0	0	0	0	0	0	2.5	0	4
123	AWACS	36	0	0	0	0	0	0	0	0	6.5	42	5
124	AWACS	43	0	0	30	0	0	0	0	0	4.5	3	4
125	AWACS	0	0	0	0	0	24	0	0	0	10.0	12	2
126	AWACS	25	0	0	1	0	0	0	0	0	3.5	0	4
127	AWACS	50	12	0	36	0	0	0	0	0	6.5	0	6
128	AWACS	0	0	0	0	0	36	0	0	0	10.0	156	4
129	AWACS	11	0	0	0	0	0	0	0	0	6.5	36	4
130	AWACS	0	40	0	0	3	0	0	0	0	6.5	36	4
131	AWACS	0	4	0	0	0	0	0	0	0	10.0	128	4
132	AWACS	12	0	0	0	0	0	0	0	0	9.5	94	3
133	AWACS	36	22	0	0	9	0	0	3	0	9.5	88	6
134	AWACS	2	0	0	0	0	0	0	0	0	1.0	0	4
135	AWACS	0	0	0	31	0	0	0	0	0	6.5	0	6

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
121	1.5	0.0	6	1.5	0.0	10	0.0	0.0	-1.5	-1.5	6	1.5	0.0
122	0.0	0.0	6	0.0	0.0	6	0.0	0.0	0.0	-1.5	0	0.0	0.0
123	1.5	-1.5	6	0.0	0.0	8	0.0	0.0	0.0	0.0	0	0.0	0.0
124	1.5	0.0	6	1.5	0.0	6	0.0	0.0	1.5	1.5	3	0.0	0.0
125	0.0	-1.5	4	0.0	-1.5	4	0.0	0.0	0.0	-1.5	2	0.0	-1.5
126	3.0	0.0	6	1.5	-1.5	10	0.0	-1.5	0.0	1.5	4	0.0	-1.5
127	3.0	-1.5	8	1.5	-1.5	10	1.5	-1.5	1.5	3.0	5	1.5	-1.5
128	1.5	-1.5	6	1.5	-1.5	10	0.0	0.0	-1.5	1.5	2	1.5	-1.5
129	1.5	0.0	6	1.5	0.0	7	3.0	0.0	0.0	0.0	0	0.0	0.0
130	3.0	-1.5	6	1.5	-1.5	10	3.0	0.0	3.0	0.0	2	1.5	-1.5
131	3.0	-1.5	6	1.5	-1.5	10	0.0	0.0	0.0	0.0	4	1.5	-1.5
132	1.5	-1.5	4	1.5	-1.5	5	1.5	-1.5	-1.5	3.0	0	0.0	0.0
133	1.5	-1.5	10	1.5	-1.5	10	3.0	0.0	1.5	3.0	2	0.0	0.0
134	3.0	0.0	5	3.0	0.0	8	3.0	0.0	1.5	1.5	0	0.0	0.0
135	1.5	0.0	3	1.5	0.0	7	0.0	0.0	1.5	1.5	4	1.5	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
121	8	1.5	0.0	10	1.5	0.0	-1.5	-1.5	7.5	6.0
122	0	0.0	0.0	0	0.0	0.0	0.0	0.0	6.0	6.0
123	0	0.0	0.0	0	0.0	0.0	0.0	0.0	6.0	6.0
124	4	0.0	-1.5	5	0.0	0.0	-1.5	1.5	7.5	6.0
125	4	0.0	-1.5	8	0.0	-1.5	0.0	0.0	4.0	2.5
126	4	0.0	0.0	6	0.0	0.0	0.0	0.0	7.5	4.5
127	7	1.5	-1.5	8	1.5	-1.5	1.5	1.5	9.5	6.5
128	4	1.5	-1.5	10	0.0	0.0	-1.5	-1.5	7.5	4.5
129	0	0.0	0.0	0	0.0	0.0	0.0	0.0	7.5	6.0
130	4	1.5	-1.5	6	1.5	-1.5	1.5	3.0	7.5	4.5
131	6	1.5	-1.5	10	0.0	0.0	0.0	0.0	7.5	4.5
132	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	5.5	2.5
133	3	0.0	0.0	4	0.0	0.0	0.0	1.5	11.5	8.5
134	0	0.0	0.0	0	0.0	0.0	0.0	1.5	8.0	5.0
135	2	1.5	0.0	6	0.0	0.0	1.5	1.5	4.5	3.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
136	AWACS	0	0	18	0	0	0	0	0	0	10.0	12	6
137	AWACS	0	0	0	12	0	0	0	0	0	3.5	0	4
138	AWACS	69	5	0	0	0	0	0	0	0	6.5	36	2
139	AWACS	9	0	0	0	0	0	0	0	0	6.5	24	2
140	407L	60	0	0	36	0	0	24	0	0	6.5	0	4
141	407L	1	0	0	0	0	0	0	0	0	1.0	0	2
142	407L	1	0	0	0	0	0	0	0	0	1.0	0	2
143	407L	0	24	0	0	0	0	0	0	0	10.0	72	6
144	AWACS	0	0	0	4	0	0	0	0	0	9.5	101	8
145	AWACS	0	0	37	0	0	0	0	0	0	10.0	80	0
146	AWACS	45	17	0	0	0	0	0	0	0	4.5	0	3
147	AWACS	24	0	0	12	0	0	0	0	0	3.5	0	3
148	AWACS	45	0	0	26	0	0	0	0	0	4.5	0	2
149	407L	24	1	0	1	0	0	0	0	0	2.0	24	1
150	AWACS	16	0	0	0	0	0	0	0	0	2.5	0	3

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
136	0.0	-3.0	10	0.0	-3.0	10	0.0	-3.0	-3.0	3.0	3	1.5	1.5
137	1.5	-1.5	4	0.0	-1.5	8	0.0	0.0	0.0	1.5	3	1.0	-1.5
138	1.5	0.0	3	1.5	0.0	4	1.5	0.0	0.0	0.0	2	1.5	0.0
139	1.5	0.0	2	1.5	0.0	4	0.0	0.0	0.0	0.0	0	0.0	0.0
140	1.5	0.0	5	1.5	0.0	7	0.0	0.0	-1.5	1.5	2	1.5	-1.5
141	3.0	1.5	3	1.5	1.5	6	1.5	1.5	-1.5	1.5	0	0.0	0.0
142	1.5	0.0	3	1.5	0.0	4	0.0	0.0	0.0	0.0	0	0.0	0.0
143	0.0	-1.5	6	0.0	-1.5	8	0.0	0.0	0.0	-1.5	2	0.0	0.0
144	3.0	0.0	8	3.0	3.0	10	3.0	0.0	-1.5	0.0	8	0.0	-1.5
145	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0.0	0.0	1	0.0	0.0
146	3.0	0.0	4	0.0	0.0	10	0.0	0.0	0.0	0.0	0	0.0	0.0
147	1.5	0.0	4	1.5	0.0	6	0.0	0.0	0.0	1.5	2	1.5	0.0
148	0.0	0.0	3	0.0	-1.5	10	0.0	0.0	0.0	0.0	2	0.0	0.0
149	0.0	0.0	2	0.0	0.0	10	0.0	0.0	0.0	1.5	1	0.0	0.0
150	1.5	0.0	4	0.0	0.0	5	0.0	0.0	1.5	1.5	0	0.0	0.0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
136	5	1.5	1.5	6	1.5	-1.5	-1.5	-3.0	10.0	7.0
137	3	1.5	0.0	8	0.0	0.0	-1.5	0.0	4.0	2.5
138	3	1.5	0.0	4	1.5	0.0	0.0	0.0	4.5	3.0
139	0	0.0	0.0	0	0.0	0.0	0.0	0.0	3.5	2.0
140	3	1.5	-1.5	5	0.0	0.0	0.0	-1.5	6.5	5.0
141	0	0.0	0.0	0	0.0	0.0	0.0	-1.5	4.5	4.5
142	0	0.0	0.0	0	0.0	0.0	0.0	0.0	4.5	3.0
143	2	0.0	0.0	4	0.0	0.0	-1.5	0.0	6.0	4.5
144	8	1.5	0.0	10	1.5	0.0	-1.5	-1.5	11.0	11.0
145	2	0.0	0.0	3	0.0	0.0	0.0	0.0	0.0	0.0
146	0	0.0	0.0	0	0.0	0.0	0.0	0.0	4.0	4.0
147	3	1.5	0.0	4	3.0	0.0	0.0	0.0	5.5	4.0
148	3	0.0	-1.5	10	0.0	0.0	0.0	0.0	3.0	1.5
149	2	0.0	0.0	10	0.0	0.0	0.0	0.0	2.0	2.0
150	0	0.0	0.0	0	0.0	0.0	0.0	1.5	4.0	4.0

OBS	SYS	Q3A	Q3B	Q3C	Q3D	Q3E	Q3F	Q3G	Q3H	Q3I	Q4	Q5	Q6
151	AWACS	12	0	0	0	0	0	0	0	0	1.5	0	2
152	AWACS	48	0	0	12	0	0	0	0	0	6.5	36	3
153	AWACS	27	2	0	0	0	0	0	0	0	3.5	0	3
154	AWACS	48	0	0	27	0	0	0	0	0	4.5	0	4
155	AWACS	0	0	0	13	0	0	0	0	0	4.0	0	3
156	AWACS	0	0	84	0	0	48	0	0	36	9.5	24	6
157	FACP	8	0	0	1	0	0	0	0	0	1.5	0	3
158	FACP	0	0	0	30	0	0	0	0	0	3.5	0	6
159	407L	10	0	0	10	0	0	0	0	0	3.5	12	3
160	407L	96	72	0	0	0	0	0	0	0	10.0	98	5
161	407L	0	9	0	0	0	0	0	0	0	10.0	15	4
162	407L	19	7	0	15	0	0	2	2	0	3.5	0	2
163	407L	28	16	0	27	16	0	27	16	0	3.5	12	5
164	407L	36	3	0	0	0	0	0	0	0	3.5	0	2
165	407L	15	1	0	4	0	0	0	0	0	2.5	0	6

OBS	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
151	0.0	0.0	3	0.0	0.0	4	0.0	0.0	0.0	0.0	0	0.0	0
152	1.5	-1.5	5	1.5	-1.5	7	3.0	-1.5	1.5	3.0	4	0.0	0
153	0.0	0.0	3	0.0	0.0	10	0.0	0.0	0.0	0.0	3	0.0	0
154	3.0	0.0	6	3.0	0.0	10	3.0	0.0	0.0	0.0	3	1.5	0
155	1.5	0.0	2	0.0	0.0	7	1.5	0.0	0.0	1.5	2	1.5	0
156	0.0	0.0	10	0.0	0.0	10	0.0	0.0	0.0	0.0	6	0.0	0
157	1.5	0.0	6	3.0	0.0	10	3.0	0.0	-3.0	0.0	2	1.5	0
158	1.5	0.0	8	0.0	-1.5	10	0.0	-1.5	-1.5	1.5	4	1.5	0
159	1.5	0.0	5	3.0	0.0	8	3.0	0.0	-1.5	0.0	3	1.5	0
160	0.0	-1.5	7	0.0	-1.5	9	0.0	-1.5	0.0	2.0	3	1.5	0
161	1.5	-1.5	6	1.5	-1.5	6	0.0	0.0	0.0	1.5	2	1.5	0
162	1.5	0.0	4	1.5	0.0	10	0.0	0.0	-1.5	0.0	2	0.0	0
163	3.0	0.0	8	0.0	0.0	8	0.0	0.0	-1.5	3.0	3	0.0	0
164	0.0	-1.5	3	0.0	0.0	4	1.5	-1.5	0.0	-1.5	2	0.0	0
165	1.5	-1.5	6	1.5	0.0	10	0.0	0.0	0.0	3.0	4	0.0	0

OBS	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
151	0	0.0	0.0	0	0.0	0.0	0.0	0.0	3.0	3.0
152	3	1.5	-1.5	4	3.0	1.5	1.5	1.5	6.5	3.5
153	3	0.0	0.0	10	0.0	0.0	0.0	0.0	3.0	3.0
154	4	1.5	0.0	6	1.5	0.0	0.0	0.0	9.0	6.0
155	2	0.0	1.5	5	1.5	0.0	0.0	0.0	2.0	2.0
156	10	0.0	0.0	10	0.0	0.0	0.0	0.0	10.0	10.0
157	3	1.5	0.0	8	1.5	0.0	-1.5	-3.0	9.0	6.0
158	7	0.0	-1.5	7	1.5	-1.5	-1.5	-1.5	8.0	6.5
159	5	3.0	0.0	8	3.0	0.0	-1.5	-1.5	8.0	5.0
160	5	1.5	-1.5	6	1.5	-1.5	0.0	0.0	7.0	5.5
161	3	1.5	0.0	3	1.5	0.0	0.0	0.0	7.5	4.5
162	2	0.0	0.0	6	0.0	0.0	-1.5	-1.5	5.5	4.0
163	5	0.0	0.0	5	0.0	0.0	-1.5	-1.5	8.0	8.0
164	3	1.5	-1.5	4	1.5	-1.5	0.0	0.0	3.0	3.0
165	6	0.0	-1.5	6	0.0	0.0	0.0	0.0	7.5	6.0

OBS	SYS	Q33A	Q33B	Q33C	Q33D	Q33E	Q33F	Q33G	Q33H	Q33I	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
166	407L	1	0	0	0	0	0	0	0	0	1.0	0	2	1.5	0.0	4	1.5	-1.5	5
167	AWACS	9	0	0	0	0	0	0	0	0	1.5	0	5	3.0	0.0	8	1.5	0.0	10
168	407L	5	2	0	0	2	0	0	2	0	6.5	0	5	3.0	-1.5	8	3.0	-1.5	10
169	407L	0	0	0	24	0	0	0	0	0	9.5	24	3	1.5	0.0	4	1.5	0.0	5

OBS	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	RADIO	TACTMAX	TACTMIN
166	1.5	0	0.0	-1.5	0	0.0	0	0	0.0	0	0	0.0	0	0.0	0.0	5.5	2.5
167	3.0	3	1.5	1.5	0	0.0	0	0	0.0	0	0	0.0	0	0.0	1.5	9.5	8.0
168	0.0	0	0.0	0.0	3	0.0	0	4	0.0	0	6	1.5	0	0.0	0.0	11.0	6.5
169	1.5	0	0.0	1.5	2	1.5	0	3	1.5	0	4	1.5	0	1.5	0.0	5.5	4.0

Analysis of Expert Responses To Determine Average Controller Maximum Control Capacity

VARIABLE	N	MEAN	STD ERROR OF MEAN	T	PR>:T:
Q20	112	3.84821429	0.15596764	24.67	0.0001
TACTMAX	112	4.70535714	0.18999610	24.77	0.0001
TACTMIN	112	3.40625000	0.16677095	20.42	0.0001
RADIO	112	-0.12053571	0.09151712	-1.32	0.1905

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SYS	3	407L AWACS FACP

NUMBER OF OBSERVATIONS IN DATA SET = 112

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Q20

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	2	2.86534993	1.43267496
ERROR	109	299.55429293	2.74820452
CORRECTED TOTAL	111	302.41964286	

MODEL F = 0.52 PR > F = 0.5952

R-SQUARE	C.V.	ROOT MSE	Q20 MEAN
0.009475	43.0790	1.65777095	3.84821429

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SYS	2	2.86534993	0.52	0.5952

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SYS	2	2.86534993	0.52	0.5952

GENERAL LINEAR MODELS PROCEDURE
T TESTS (LSD) FOR VARIABLE: Q20

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=109 MSE=2.7482
CRITICAL VALUE OF T=1.98197
LEAST SIGNIFICANT DIFFERENCE=1.2966

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=12.8432

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	SYS
A	4.5000	6	FACP
A			
A	3.8295	88	AWACS
A			
A	3.7222	18	407L

GENERAL LINEAR MODELS PROCEDURE
DEPENDENT VARIABLE: TACTMAX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	2	5.13537157	2.56768579
ERROR	109	443.64141414	4.07010472
CORRECTED TOTAL	111	448.77678571	

MODEL F = 0.63 PR > F = 0.5341

R-SQUARE	C.V.	ROOT MSE	TACTMAX MEAN
0.011443	42.8756	2.01745005	4.70535714

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SYS	2	5.13537157	0.63	0.5341

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SYS	2	5.13537157	0.63	0.5341

GENERAL LINEAR MODELS PROCEDURE
T TESTS (LSD) FOR VARIABLE: TACTMAX

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=109 MSE=4.0701
CRITICAL VALUE OF T=1.98197
LEAST SIGNIFICANT DIFFERENCE=1.5779

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=12.8432

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	SYS
A	5.5000	6	FACP
A	4.8889	18	407L
A	4.6136	88	AWACS

GENERAL LINEAR MODELS PROCEDURE
DEPENDENT VARIABLE: TACTMIN

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	2	0.05886995	0.02943497
ERROR	109	345.70675505	3.17162161
CORRECTED TOTAL	111	345.76562500	

MODEL F =	0.01	PR > F = 0.9908

R-SQUARE	C.V.	ROOT MSE	TACTMIN MEAN
0.000170	52.2834	1.78090472	3.40625000

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SYS	2	0.05886995	0.01	0.9908

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SYS	2	0.05886995	0.01	0.9908

GENERAL LINEAR MODELS PROCEDURE
T TESTS (LSD) FOR VARIABLE: TACTMIN

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=109 MSE=3.17162
CRITICAL VALUE OF T=1.98197
LEAST SIGNIFICANT DIFFERENCE=1.3929

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=12.8432

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	SYS
A	3.5000	6	FACP
A	3.4034	88	AWACS
A	3.3889	18	407L

Appendix C. Slam Simulation Code

SLAM NETWORK CODE

```
GEN,CLEMENTS,WD1,5/12/87,3,,,,,,72;
LIMITS,6,16,1800;
RECORD,TNOW,SIM_TIME,8,P;
VAR,NNQ(1),U,UNPAIRED;
VAR,NNQ(5),P,PAIRED;
INTLC,XX(2)=0,XX(11)=0,XX(12)=0,XX(13)=0,XX(14)=0,XX(15)=0,
      XX(16)=0,XX(17)=0,XX(18)=0,XX(19)=0,XX(20)=0,XX(21)=0,
      XX(22)=0,XX(3)=0,XX(4)=0,XX(6)=0;
PRIORITY/2,LVF(11)/1,LVF(1)/5,LVF(11);
;       *** TIME UNIT IS ONE MINUTE ***
NETWORK;
       RESOURCE/F11(4),1/P11(3),1/A11(3),1/P21(4),1/F21(4),1/
                P31(3),1/F12(3),1/P12(4),1/A12(4),1/P22(4),1/
                F22(4),1/P32(4),1/CAP(1),3;
;
;       *** FLY ENEMY AIRCRAFT ***
;
      CREATE,EXPON(XX(1),6),0,1;
      ASSIGN,ATRIB(2)=2;          ENEMY AIRCRAFT TYPE
      ASSIGN,XX(2)=XX(2)+1,ATRIB(11)=XX(2); TRACK NUMBER
      ASSIGN, ATRIB(15)=1,ATRIB(13)=1;
;
      EVENT,1;                    SET ATRIBS
RDET  EVENT,2;                    RADAR DETECTION
      ACT,ATRIB(12);
;
ID    GOON;
      ACT,TRIAG(0.8,2.5,4.0,2),.9,FLY;
      ACT,.2,.1,ID;
;
FLY   GOON,2;
      ACT,,,HOLD;
      ACT,,,NEXT;
;
HOLD  AWAIT(1),ALLOC(1);
      ACT,.1;
      EVENT,8;                    INTERCEPT (IN FORTRAN CODE)
      TERM;
;EGAG  QUEUE(2);                  (IN FORTRAN CODE)
;
NEXT  EVENT,3;                    DETERMINE NEXT EVENT
      ACT,.001,ATRIB(13).NE.3,TURN;
      ACT,,ATRIB(13).EQ.3,REXIT;
;
TURN  EVENT,4;                    ROUTE TURN POINT
      ACT,ATRIB(12),,NEXT;
;
REXIT TERM;
```

```
;
;
;                   *** SET ENEMY CREATION RATE ***
;
      CREATE,240;
LOOP  ASSIGN,XX(1)=.10;
      ACT,210;
      ASSIGN,XX(1)=.05;
      ACT,30;
      TERM;
;
;
;                   *** FLY FRIENDLY AIRCRAFT ***
;
      CREATE,.01,0,1,120;          CREATE  AIR DEFENSE INTERCEPTORS
      ASSIGN,ATRIB(2)=1;           TYPE FRIENDLY
      ASSIGN,XX(6)=XX(6)+1,
             ATRIB(16)=XX(6);
      EVENT,1;                     SET ATRIBS
;
;WAIT  AWAIT(3),ALLOC(2);          WAIT UNTIL NEEDED ON CAP,FILL CAPS
;      ACT;
      QUEUE(4);                    CAP FILE, WAITING TO BE PAIRED
;
;PAIR  QUEUE(5);                   PAIRED QUEUE (IN FORTRAN CODE)
;
;          ***END OF PAIRING, INTERCEPTOR CONTINUES IN FORTRAN***
      ENDNETWORK;
INIT,0,480;
SIMULATE;
SEEDS,428956419(5),1954324947(6),1145661099(7),1835732737(8),
      794161987(9),1329531353(10),200496737(1),633816299(2),
      1410143363(3),1282538739(4);
SIMULATE;
SEEDS,428956419(4),1954324947(5),1145661099(6),1835732737(7),
      794161987(8),1329531353(9),200496737(10),633816299(1),
      1410143363(2),1282538739(3);
SIMULATE;
FIN;
```

SLAM FORTRAN CODE

```
      PROGRAM MAIN
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     3,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=150000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C       ==============================================================
C       ==============================================================
C
      SUBROUTINE INTLC
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
```

```
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     3,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS,I,J,K
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C       THIS ROUTINE INITIALIZES THE AIR DEFENSE NETWORK BY SETTING
C       THE REGION BOUNDRIES, RADAR TYPES AND LOCATIONS, ENEMY BASES
C       AND PENETRATION ROUTES, FRIENDLY BASES AND CAP POINTS, AND
C       AIRCRAFT TYPES AND SPECIFICATIONS.
C
C       /////////////////////////////////////////////////////
C               RADAR TYPE DATA
C       /////////////////////////////////////////////////////
C
      OPEN (11,FILE ='RADSPECS.DAT',STATUS ='OLD')
      REWIND 11
C
      READ (11,*) NUMTYPE
C      PRINT *,'RADAR SPECS DATA...NUMTYPE =',NUMTYPE
      DO 10 I=1,NUMTYPE
        READ (11,*) (RADSPECS(I,J),J=1,13)
10    CONTINUE
C
C       /////////////////////////////////////////////////////
C               FRIENDLY AIRCRAFT DATA
C       /////////////////////////////////////////////////////
C
      OPEN (12,FILE='AI.DAT',STATUS='OLD')
      REWIND 12
C
      READ (12,*) NUMAI
C      PRINT *,'AI DATA...NUMAI =',NUMAI
      DO 20 I=1,NUMAI
        READ (12,*) (AISPECS(I,J),J=1,6)
C       PRINT *, (AISPECS(I,J),J=1,6)
20    CONTINUE
C
C       ***READ MISSILE DATA***
C
      READ (12,*) RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,RHPK,RTPK
      READ (12,*) HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,HHPK,HTPK
C
C      PRINT *,'MISSILE PARAMETERS:'
```

```
C        PRINT *,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,RHPK,RTPK
C        PRINT *,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,HHPK,HTPK
C
C         ///////////////////////////////////////////////////
C                 ENEMY AIRCRAFT DATA
C         ///////////////////////////////////////////////////
C
       OPEN (13,FILE='HOSSPECS.DAT',STATUS='OLD')
       REWIND 13
C
       READ (13,*) NUMHOS
C        PRINT *,'HOSTILE AIRCRAFT DATA...NUMHOS =',NUMHOS
       DO 30 I=1,NUMHOS
         READ (13,*) (HOSSPECS(I,J),J=1,5)
C        PRINT *, (HOSSPECS(I,J),J=1,5)
30     CONTINUE
C
C         ///////////////////////////////////////////////////
C                 MODEL SCENARIO DATA
C         ///////////////////////////////////////////////////
C
       OPEN (14,FILE='SCENARIO.DAT',STATUS='OLD')
       REWIND 14
C
C        PRINT *,'                  *** MODEL SCENARIO ***'
         READ (14,*) (MODEL(I),I=1,5)
C        PRINT *,'AWACS=',MODEL(1),' SYS=',MODEL(2),' CONTROL=',MODEL(3)
C      1         ,' ATTACK=',MODEL(4),' A/C TYPE=',MODEL(5)
C
C         //////////////////////////////////////////////////
C                 CAP POINT LOCATIONS
C         //////////////////////////////////////////////////
C
       OPEN (15,FILE='CAPS.DAT',STATUS='OLD')
       REWIND 15
       READ (15,*) NUMCAP
C        PRINT *,'FRIENDLY CAPS DATA...NUMCAP =',NUMCAP
C
       DO 50 I=1,NUMCAP
         READ (15,*) (CAPCOORD(I,J),J=1,3)
C        PRINT *, (CAPCOORD (I,J),J=1,3)
50     CONTINUE
C
C         /////////////////////////////////////////////////
C                 RADAR LOCATIONS
C         ////////////////////////////////////////////////
C
       OPEN (16,FILE='RADLOC.DAT',STATUS='OLD')
       REWIND 16
C
       READ (16,*) NUMRADAR
C        PRINT *,'FRIENDLY RADAR LOCATION DATA...NUMRADAR =',NUMRADAR
       DO 60 I=1,NUMRADAR
```

```
        READ (16,*) (RADCOORD(I,J),J=1,4)
60    CONTINUE
C
C       ///////////////////////////////////////////////////
C               HOSTILE PENETRATION ROUTES
C       ///////////////////////////////////////////////////
C
      OPEN (17,FILE='ROUTES.DAT',STATUS='OLD')
      REWIND 17
      K = 0
C
      READ (17,*) NUMROUTES
      DO 70 I=1,NUMROUTES
C      PRINT *,'PENETRATION ROUTE DATA...NUMROUTES =',NUMROUTES
        READ (17,*) RNUM,TURNS
        DO 80 J=1,TURNS
          K=K+1
          READ (17,*) (ROUTECOORD(K,L),L=1,3)
C         PRINT *, (ROUTECOORD(K,L),L=1,3)
80      CONTINUE
70    CONTINUE
C
C
      RETURN
      END
C
C       ============================================================
C       ============================================================
C
      SUBROUTINE ALLOC(IALL,IFLAG)
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPX
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,ROUTE
     2,FTR(20),DIFFX,DIFFY,DIST,AITYPE,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT
     3,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),WD,LOOP,RANK,
     1ROUTECOORD(100,5),TURNS,I,J,CAP,IFLAG,IALL
```

```
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C       THIS ROUTINE MATCHES A HOSTILE AIRCRAFT WITH AN INTERCEPTOR
C       UNDER THE CONTROL OF AN AIR WEAPONS CONTROLLER.  IF NO
C       INTERCEPTOR OR CONTROLLER IS AVAILABLE, THE HOSTILE AIRCRAFT
C       'CONTINUES ITS ROUTE' UNOPPOSED UNTIL AN INTERCEPT CAN
C       BE MADE.  THIS ALLOCATION IS MADE DEPENDANT UPON SCENARIO
C       SYSTEM CONFIGURATION AND THE ROUTE THE HOSTILE IS FLYING
C       ACCORDING TO THE FOLLOWING RULES;
C
C       ROUTE        PRI CONTROL     SEC CONTROL     TERT CONTROL
C       =====        ===========     ===========     ============
C        1,2            FACP *1         CRP *1          AWACS
C         3             CRP *1          FACP *1         AWACS
C         4             CRP *1          CRP *2          AWACS
C         5             AWACS           CRP *1          CRP *2
C         6             CRP *2          CRP *1          AWACS
C         7             CRP *2          FACP *2         AWACS
C        8,9            FACP *2         CRP *3          AWACS
C        10             AWACS           CRP *3          FACP *2
C       11,12           CRP *3          AWACS           NONE
C
C       THE SECOND SECTION OF THIS ROUTINE DETERMINES WHICH CAP
C       LOCATIONS NEED TO BE FILLED, AND FILLS THEM SEQUENTIALLY
C       UP TO THE MAXIMUM CAPACITY OF THE CAP.
C
C       ================================================
C       *** ASSIGNING THE CONTROLLER AND INTERCEPTOR ***
C       ================================================
C
1     IFLAG = 0
C      PRINT *,'CALLING ALLOC....TNOW=',TNOW,' IFLAG=',IFLAG,'ROUTE=',
C     1         ROUTE
C
C       *** CHECKING FOR INTERCEPTORS AVAILABLE ***
      J = NNQ(1)
      DO 4 I=1,J
        LOOP = 0
C        PRINT *,'* HOSTILES WAITING TO BE PAIRED=',J,' I=',I
        CALL COPY(I,1,ATRIB)
        ROUTE = ATRIB(7)
C
      IF (NNQ(4).EQ.0) THEN
        PRINT *,'TNOW=',TNOW,' THERE ARE NO INTERCEPTORS AVAILABLE.'
        GO TO 90
      END IF
C
C       *** CHECKING FOR CONTROLLER AVAILABLE ***
C
      IF (ROUTE.LE.2) THEN
        GO TO 10
```

```
      ELSE IF (ROUTE.LE.4) THEN
        GO TO 20
      ELSE IF (MODEL(1).EQ.1 .AND. (ROUTE.EQ.5 .OR. ROUTE.EQ.10)) THEN
        GO TO 30
      ELSE IF (ROUTE.LE.7)THEN
        GO TO 40
      ELSE IF (ROUTE.LE.9) THEN
        GO TO 50
      ELSE
        GO TO 60
      END IF
C
C       *** FACP *1 ***
C
10    IF (LOOP.GT.10) THEN
        GO TO 4
      ELSE IF (NNRSC(1).GT.0) THEN
        WD = 1
        GO TO 70
      ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(7).GT.0) THEN
        WD =     GO TO 4
      ELSE IF (NNRSC(1).GT.0) THEN
        WD = 1
        GO TO 70
      ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(7).GT.0) THEN
        WD = 7
        GO TO 70
      ELSE IF (MODEL(2).EQ.1 .AND. ROUTE.LE.2) THEN
        LOOP = LOOP + 1
        GO TO 20
      ELSE IF (MODEL(1).EQ.1 .AND. MODEL(2).EQ.1) THEN
        LOOP = LOOP + 1
        GO TO 30
      ELSE
        GO TO 4
      END IF
C
C       *** CRP *1 ***
C
20    IF (LOOP.GT.10) THEN
        GO TO 4
      ELSE IF (NNRSC(2).GT.0) THEN
        WD = 2
        GO TO 70
      ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(8).GT.0) THEN
        WD = 8
        GO TO 70
      ELSE IF (ROUTE.LE.2 .AND. MODEL(1).EQ.1) THEN
        LOOP = LOOP + 1
        GO TO 30
      ELSE IF (ROUTE.EQ.3) THEN
        LOOP = LOOP + 1
        GO TO 10
```

```
      ELSE IF (ROUTE.LE.5) THEN
        LOOP = LOOP + 1
        GO TO 40
      ELSE IF (ROUTE.EQ.6 .AND. MODEL(1).EQ.1) THEN
        LOOP = LOOP + 1
        GO TO 30
      ELSE
        GO TO 4
      END IF
C
C       *** AWACS ***
C
30    IF (LOOP.GT.10) THEN
        GO TO 4
      ELSE IF (NNRSC(3).GT.0) THEN
        WD = 3
        GO TO 70
      ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(9).GT.0) THEN
        WD = 9
        GO TO 70
      ELSE IF (ROUTE.EQ.5) THEN
        LOOP = LOOP + 1
        GO TO 20
      ELSE IF (ROUTE.EQ.10) THEN
        LOOP = LOOP + 1
        GO TO 60
      ELSE
        GO TO 4
      END IF
C
C       *** CRP *2 ***
C
40    IF (LOOP.GT.10) THEN
        GO TO 4
      ELSE IF (NNRSC(4).GT.0) THEN
        WD = 4
        GO TO 70
      ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(10).GT.0) THEN
        WD = 10
        GO TO 70
      ELSE IF (ROUTE.EQ.4 .AND. MODEL(1).EQ.1) THEN
        LOOP = LOOP + 1
        GO TO 30
      ELSE IF (ROUTE .EQ.6) THEN
        LOOP = LOOP + 1
        GO TO 20
      ELSE IF (ROUTE.EQ.7 .AND. MODEL(2).EQ.1) THEN
        LOOP = LOOP + 1
        GO TO 50
      ELSE
        GO TO 4
      END IF
C
```

```
C         *** FACP *2 ***
C
50      IF (LOOP.GT.10) THEN
          GO TO 4
        ELSE IF (NNRSC(5).GT.0) THEN
          WD = 5
          GO TO 70
        ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(11).GT.0) THEN
          WD = 11
          GO TO 70
        ELSE IF (MODEL(1).EQ.1 .AND. MODEL(2).EQ.1 .AND. ROUTE.EQ.7) THEN
          LOOP = LOOP + 1
          GO TO 30
        ELSE IF (MODEL(2).EQ.1 .AND. (ROUTE.EQ.8 .OR. ROUTE.EQ.9)) THEN
          LOOP = LOOP + 1
          GO TO 60
        ELSE
          GO TO 4
        END IF
C
C         *** CRP *3 ***
C
60      IF (LOOP.GT.10) THEN
          GO TO 4
        ELSE IF (NNRSC(6).GT.0) THEN
          WD = 6
          GO TO 70
        ELSE IF (MODEL(3).EQ.1 .AND. NNRSC(12).GT.0) THEN
          WD = 12
          GO TO 70
        ELSE IF (MODEL(2).EQ.1 .AND. ROUTE.EQ.10) THEN
          LOOP = LOOP + 1
          GO TO 50
        ELSE IF (MODEL(1).EQ.1 .AND. ROUTE.LE.9) THEN
          LOOP = LOOP + 1
          GO TO 30
        ELSE IF (MODEL(1).EQ.1 .AND. ROUTE.GE.11) THEN
          LOOP = LOOP + 1
          GO TO 30
        ELSE
          GO TO 4
        END IF
C
C         -------------------------------
C         *** ASSIGNING INTERCEPTORS ***
C         -------------------------------
C
70      CALL COPY(1,4,FTR)
        CAP = INT(ROUTE)
        FTR(13) = CAP
        FTR(5) = CAPCOORD(CAP,2)
        FTR(6) = CAPCOORD(CAP,3)
        DIFFX = FTR(5) - ATRIB(5)
```

```
      DIFFY = FTR(6) - ATRIB(6)
      DIST = SQRT((DIFFX**2) + (DIFFY**2))
C
C       *** CHECK IF HOSTILE EXITING -- NO LONGER A THREAT **
C
      IF ((ATRIB(16).GE.45).AND.(ATRIB(16).LE.135).AND.
     1              (DIST.GT.10))THEN
C       PRINT *,'HOSTILE A/C GOING HOME -- OUT OF RANGE'
        ATRIB(13) = 3
        GO TO 4
C
C       ***CHECK HOSTILE WITHIN 50 MILES***
C
      ELSE IF (DIST .GT. 50) THEN
        GO TO 4
C
      ELSE
C       *** ASSIGN INTERCEPTOR AND CONTROLLER ***
        CALL SEIZE(WD,1)
        GO TO 3
      END IF
C
4     CONTINUE
      RETURN
C
C       ***PUT HOSTILE TRACK NUMBER IN INTERCEPTOR ATRIBS***
C
3     FTR(14) = 1
      FTR(15) = WD
      FTR(11) = ATRIB(11)
      CALL FILEM(5,FTR)
      CALL RMOVE(1,4,FTR)
      IFLAG = I
C
C       ***SHOW HOSTILE PAIRED AND PLACE IN PAIRED QUEUE(2)***
C
      ATRIB(13)=2
      XX(4) = XX(4) + 1
      CALL FILEM(2,ATRIB)
C
C      PRINT *,'LEAVING ALLOC....IFLAG=',IFLAG
90    RETURN
C
      END
C       ==============================================================
C       ==============================================================
C
      SUBROUTINE EVENT(I)
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
```

```
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT
     3,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C       THIS ROUTINE CALL THE CORRECT FORTRAN SUBROUTINE BASED ON THE
C       EVENT CODE, I, DESIGNATED IN THE SLAM NETWORK OR IN A DISCRETE
C       SUBROUTINE.
C
      GO TO (1,2,3,4,5,6,7,8),I
C
C1     PRINT *,'CALLING SET_ATRIB'
1      CALL SET_ATRIB
      RETURN
C
C2     PRINT *,'CALLING RADAR_DETECT'
2      CALL RADAR_DETECT
      RETURN
C
C3     PRINT *,'CALLING CHOOSE'
3      CALL CHOOSE
      RETURN
C
C4     PRINT *,'CALLING TURN_PT'
4      CALL TURN_PT
      RETURN
C
C6     PRINT *,'CALLING CAP'
6      CALL CAP
      RETURN
C
C7     PRINT *,'CALLING ENGAGE'
7      CALL ENGAGE
      RETURN
C
C8     PRINT *,'CALLING INTERCEPT'
```

```
8      CALL INTERCEPT
       RETURN
C
5      RETURN
C
       END
C
C        ==========================================================
C        ==========================================================
C
       SUBROUTINE SET_ATRIB
C
       DIMENSION NSET(150000)
       INCLUDE 'PARAM.INC'
C
       COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
      1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
      2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
       COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
      1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
       COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
       COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
      1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
       REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),NUM,DIST,
      1MINSPD,SPEED,MAXSPD,X,Y,RADAR(15,5),NUMTYPE,NUMHOS,NUMCAP,
      2NUMRADAR,NUMROUTES,NUMAI,ANGLE,PI,AITYPE,RHMAX,RHOPT
      3,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,RHPK,RTPK
      4,HHPK,HTPK
C
       INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
      1ROUTECOORD(100,5),TURNS,N,XCOORD1,XCOORD2,YCOORD1,YCOORD2
      2,ROUTE,TURNPT
C
       COMMON QSET(150000)
       EQUIVALENCE (NSET(1),QSET(1))
       PARAMETER (PI = 3.14159265)
C
C        THIS ROUTINE SETS THE ATTRIBUTES OF BOTH FRIENDLY AND
C        ENEMY AIRCRAFT ENTITIES.  THIS IS ACCOMPLISHED THROUGH
C        READING FORTRAN ARRAYS THAT WERE ESTABLISHED BY THE
C        INTLC SUBROUTINE.
C
C        ///////////////////////////////////////////////////////
C        ********  SET ENEMY ATRIBUTES  ********
C        ///////////////////////////////////////////////////////
C
       N=0
       IF (ATRIB(2).EQ.1) THEN
         GO TO 100
```

```
      END IF
C
C               *** SETTING ROUTE AND START POINT ***
C
      IF (MODEL(4).EQ.0) THEN
        NUM = DRAND(9)
      ELSE
        NUM = TRIAG(0.0,0.6667,1.0,9)
      END IF
C
15    N = N + 1
      IF (NUM.LE.(N/NUMROUTES)) THEN
        ATRIB(5) = ROUTECOORD(N,2)
        ATRIB(6) = ROUTECOORD(N,3)
        ATRIB(7) = N
      ELSE
        GO TO 15
      END IF
C               *** SETTING TYPE AND SPEED ***
C
      NUM = DRAND(9)
      N = 0
26    N = N + 1
      IF (NUM.LE.(N/NUMHOS)) THEN
        ATRIB(2) = 20 + N
        MINSPD = HOSSPECS(N,2)
        SPEED = HOSSPECS(N,3)
        MAXSPD = HOSSPECS(N,4)
        ATRIB(3) = INT(TRIAG(MINSPD,SPEED,MAXSPD,9))
      ELSE
        GO TO 26
      END IF
C
C       *** SETTING INITIAL HEADING ***
      I = 1
      ROUTE = ATRIB(7)
C      PRINT *,'PENETRATION ROUTE =',ROUTE
      TURNPT = ATRIB(15)
C       *** DETERMINE THE DISTANCE TO THE NEXT TURNPOINT ***
C
C      PRINT *,'ROUTECOORD ARRAY:'
C      DO 20 J=1,50
C       PRINT *,(ROUTECOORD(J,K),K=1,3)
C20    CONTINUE
C
10    IF (ROUTECOORD(I,1).EQ.ROUTE) THEN
        ATRIB(5) = ROUTECOORD(I,2)
        ATRIB(6) = ROUTECOORD(I,3)
        X = ROUTECOORD(I+1,2) - ATRIB(5)
        Y = ROUTECOORD(I+1,3) - ATRIB(6)
        DIST = SQRT((X**2)+(Y**2))
        GO TO 11
      ELSE
```

```
C         PRINT *,'SEARCHING ... ROUTE=',ROUTECOORD(I,1),' I=',I
          I = I + 1
          GO TO 10
        END IF
C
C         *** UPDATE ATRIBS (NEXT TURNPT, TIME TO NEXT TURNPT) ***
C
11      ATRIB(12) = (DIST/ATRIB(3))*60
C
C        PRINT *,'                              TNOW=',TNOW
C        PRINT *,'DIST =',DIST,'ATRIB(5) =',ATRIB(5),'ATRIB(6) =',
C       1ATRIB(6)
C        PRINT *,'ATRIB(12) =',ATRIB(12),'TURN PT =',ATRIB(15)
C
C         *** DETERMINE NEW HEADING ***
C
        ANGLE = (ACOS(X/DIST))*(180/PI)
C
        IF (X.GE.0) THEN
          GO TO 16
        ELSE
          GO TO 25
        END IF
C
16      IF (Y.GE.0) THEN
          ATRIB(16) = 90 - ANGLE
        ELSE
          ATRIB(16) = 90 + ANGLE
        END IF
        GO TO 35
C
25      IF (Y.GE.0) THEN
          ATRIB(16) = 450 - ANGLE
        ELSE
          ATRIB(16) = 90 + ANGLE
        END IF
C
C35      PRINT *,'HEADING =',ATRIB(16)
C
C                 *** SETTING ALTITUDE AND FLT SIZE ***
C
35      ATRIB(4) = INT(TRIAG(0.1,2.0,25.0,9)*1000)
        ATRIB(9) = INT(UNFRM(.001,.004,9)*1000)
C
C                 *** SETTING ENEMY SYSTEM EXIT TIME ***
C
        DIST = 0
        I = 1
C
40      IF ((ROUTECOORD(I,1).EQ.ATRIB(7)).AND.(ROUTECOORD(I+1,1).EQ.
     +      ATRIB(7))) THEN
          XCOORD1 = ROUTECOORD(I,2)
          YCOORD1 = ROUTECOORD(I,3)
```

```
          XCOORD2 = ROUTECOORD(I+1,2)
          YCOORD2 = ROUTECOORD(I+1,3)
          X = XCOORD2 - XCOORD1
          Y = YCOORD2 - YCOORD1
          DIST = DIST + SQRT((X**2) + (Y**2))
          I = I + 1
C
C         PRINT *,'ROUTE=',ROUTECOORD(I,1),'X1=',XCOORD1,'Y1=',YCOORD1
C         PRINT *,'X2=',XCOORD2,'Y2=',YCOORD2,'DIST=',DIST
          GO TO 40
C
        ELSE IF (ROUTECOORD(I,1).LT.ATRIB(7)) THEN
          I = I + 1
          GO TO 40
C
        ELSE
          GO TO 50
        END IF
C
50      ATRIB(14) = TNOW + (DIST/ATRIB(3))*60
C
C        PRINT *,'TNOW=',TNOW,'TYPE=',ATRIB(2),'SPEED=',ATRIB(3)
C        PRINT *,'X COORD=',ATRIB(5),'Y COORD=',ATRIB(6)
C        PRINT *,'FLIGHT SIZE=',ATRIB(9),'ALTITUDE =',ATRIB(4)
C        PRINT *,'SYSTEM EXIT TIME = ATRIB(14) =',ATRIB(14)
C
        RETURN
C         ///////////////////////////////////////////////////////////////
C         ************* SET FRIENDLY AIRCRAFT ATRIBUTES ***********
C         ///////////////////////////////////////////////////////////////
C
100     IF (MODEL(5).EQ.1) THEN
          N = 1
        ELSE
          N = 2
        END IF
C
C                 *** SET TYPE, SPEED, # MISSILES ***
C
60      ATRIB(2) = 10 + N
        ATRIB(3) = AISPECS(N,3)
        ATRIB(9) = AISPECS(N,4)
        ATRIB(10) = AISPECS(N,5)
C
C        PRINT *,'TNOW=',TNOW,'TYPE=',ATRIB(2),'SPEED=',ATRIB(3)
C        PRINT *,'# AIM-7=',ATRIB(9),'# AIM-9=',ATRIB(10)
C        PRINT *,'LEAVING SET_ATRIB'
        RETURN
        END
C
C         ============================================================
C         ============================================================
C
```

```
      SUBROUTINE CHOOSE
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT
     3,RHPK,RTPK,HHPK,HTPK,TRACK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS,RANK
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
      TRACK = ATRIB(11)
C
C      PRINT *,'SEARCHING PAIRED FILE'
      RANK = NFIND(1,2,11,0,TRACK,0)
      IF (RANK .GT. 0) THEN
        CALL RMOVE(RANK,2,ATRIB)
      ELSE
C
C       PRINT *,'SEARCHING UNPAIRED FILE'
        RANK = NFIND(1,1,11,0,TRACK,0)
        CALL RMOVE(RANK,1,ATRIB)
      END IF
C
C       *** CHECK FOR KILLED HOSTILE ***
C      PRINT *,'ATRIB(13)=',ATRIB(13)
      IF (ATRIB(13).EQ.3) THEN
C        PRINT *,'HOSTILE KILLED -- PULLED FROM SYSTEM'
        GO TO 10
      END IF
C
C       *** CHECK FOR HOSTILE RTB ***
      IF (TNOW .GE. ATRIB(14)) THEN
        ATRIB(13) = 3
C       PRINT *,'EXIT TIME...TNOW =',TNOW
C       PRINT *,'HOSTILE PULLED FROM SYSTEM'
```

```
          GO TO 10
        END IF
C
C         *** NO-KILL/NO-EXIT --- PUT BACK INTO SYSTEM ***
        IF (ATRIB(13) .EQ. 1) THEN
          CALL FILEM(1,ATRIB)
        ELSE
          CALL FILEM(2,ATRIB)
        END IF
C
C10      PRINT *,'LEAVING CHOOSE'
10        RETURN
        END
C
C         ==============================================================
C         ==============================================================
C
        SUBROUTINE INTERCEPT
C
        DIMENSION NSET(150000)
        INCLUDE 'PARAM.INC'
C
        COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
       1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
       2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
        COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
       1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
        COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
        COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
       1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
        REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
       1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,TRACK
       2,FTR(20),FTRX,FTRY,TGTX,TGTY,DIFFX,DIFFY,LOS,TLOS,CONVERT,PI
       3,TGTSPD,TGTHDG,ANGLE,TGTANG,VTGTX,VTGTY,FTRANG,VFTRX,VFTRY
       4,XSPD,TIME,TIME1,DIST,RAD,ANGLE1,FTRSPD,AITYPE,ASPECT
       5,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT
       6,RHPK,RTPK,HHPK,HTPK,HDG,SPD
C
        INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
       1ROUTECOORD(100,5),TURNS,QUAD,RANK,TAIL
C
        COMMON QSET(150000)
        EQUIVALENCE (NSET(1),QSET(1))
C
        PARAMETER (PI=3.14159265)
C
C         ***FIND PAIRED INTERCEPTOR***
C
        TRACK = ATRIB(11)
```

```
      RANK = NFIND(1,5,11,0,TRACK,0)
C      PRINT *,NNQ(5),'INTERCEPTORS ARE IN QUEUE #5'
      CALL RMOVE(RANK,5,FTR)
C
C        *** UPDATE HOSTILE POSITION ***
C
      CONVERT = 180/PI
      TGTX = ATRIB(5)
      TGTY = ATRIB(6)
      TIME = TNOW - ATRIB(8)
      SPD = (ATRIB(3))/60
C
      IF (TIME .GT. 0) THEN
        HDG = (2.5 * PI) - (ATRIB(16)/CONVERT)
        ATRIB(5) = TGTX + (SPD * TIME * COS(HDG))
        ATRIB(6) = TGTY + (SPD * TIME * SIN(HDG))
      END IF
C
C        ***SET UP CONSTANTS***
C
      FTRX = FTR(5)
      FTRY = FTR(6)
      TGTX = ATRIB(5)
      TGTY = ATRIB(6)
      TGTSPD = ATRIB(3)
      TGTHDG = ATRIB(16)
      FTRSPD = 1.2 * TGTSPD
C
C        *** SETTING INTERCEPTION SPEED ***
      TYPE = FTR(2) - 10
      IF (FTRSPD .GT. AISPECS(TYPE,2)) THEN
        FTRSPD = AISPECS(TYPE,2)
        FTR(3) = FTRSPD
      ELSE
        FTR(3) = FTRSPD
      END IF
C
C        ***DETERMINE LINE OF SIGHT (LOS) BETWEEN FTR AND TGT***
C
      DIFFX = FTRX - TGTX
      DIFFY = FTRY - TGTY
C
      IF (DIFFX .EQ. 0) THEN
        GO TO 10
      ELSE
        RAD = DIFFY/DIFFX
        ANGLE1 = ABS(ATAN(RAD))
        ANGLE = ANGLE1 * CONVERT
C       PRINT *,'RAD=',RAD,'ANGLE1=',ANGLE1,'ANGLE=',ANGLE
      END IF
C
C        ***DETERMINE TGT QUADRANT AND LOS RELATIVE TO FTR***
C
```

```
10    IF (FTRX .EQ. TGTX) THEN
        QUAD = 0
        IF (FTRY .GE.TGTY) THEN
          LOS = 360
          TLOS = 180
        ELSE
          LOS = 180
          TLOS = 360
        END IF
C
      ELSE IF (FTRX.LT.TGTX .AND. FTRY.LE.TGTY) THEN
        QUAD = 1
        LOS = 90 - ANGLE
        TLOS = LOS + 180
C
      ELSE IF (FTRX.LT.TGTX .AND. FTRY.GT.TGTY) THEN
        QUAD = 2
        LOS = 90 + ANGLE
        TLOS = LOS + 180
C
      ELSE IF (FTRX.GT.TGTX .AND. FTRY.GT.TGTY) THEN
        QUAD = 3
        LOS = 270 - ANGLE
        TLOS = LOS - 180
C
      ELSE
        QUAD = 4
        LOS = 270 + ANGLE
        TLOS = LOS - 180
C
      END IF
C
C       ***BREAK TGT VECTOR INTO COMPONENTS***
C
      TGTANG = (ABS(LOS-TGTHDG))/CONVERT
      VTGTX = TGTSPD * COS(TGTANG)
      VTGTY = TGTSPD * SIN(TGTANG)
C
C       ***DETERMINE INTERCEPT HEADING***
C
      FTRANG = (ASIN(VTGTY/FTRSPD)) * CONVERT
C
      IF (TGTHDG .GT. TLOS) THEN
        FTR(7) = LOS - FTRANG
      ELSE
        FTR(7) = LOS + FTRANG
      END IF
C
C      PRINT *,'TNOW=',TNOW,' FTRX=',FTRX,' FTRY=',FTRY
C      PRINT *,'                      TGTX=',TGTX,' TGTY=',TGTY
C      PRINT *,'LOS=',LOS,' TGT HDG=',TGTHDG,' FTRANG=',FTRANG
C
C       ------------------------------------
```

```
C         ***DETERMINE TIME TO INTERCEPT***
C         ------------------------------------
      VFTRY = VTGTY
      VFTRX = SQRT((FTRSPD**2) - (VFTRY**2))
      XSPD = ABS(VTGTX) + VFTRX
      DIST = SQRT((DIFFX**2) + (DIFFY**2))
C
C            **CHECK FOR ASPECT ANGLE**
      ASPECT = ABS(ATRIB(16) - FTR(7))
C      PRINT *,'ASPECT ANGLE =',ASPECT
C
      IF ((ASPECT .LE. 60) .OR. (ASPECT .GE. 300)) THEN
C       *TAIL ASPECT*
        TAIL = 1
      ELSE
C       *HEAD ASPECT*
        TAIL = 0
      END IF
C           **CHECK FOR RADAR/HEAT ENGAGEMENT**
      IF (FTR(9) .EQ. 0) THEN
        GO TO 20
      ELSE IF ((TAIL.EQ.1).AND.(DIST.LE.HTMAX).AND.(FTR(10).GT.0))
     1                  THEN
        GO TO 20
      ELSE IF ((DIST.LE.HHMAX).AND.(FTR(10).GT.0).AND.(DRAND(9).GT.
     1            (.5))) THEN
C                *RADAR ENGAGEMENT*
      ELSE IF (TAIL.EQ.0) THEN
        IF (DIST.GE.RHMAX) THEN
          SHOOT = TRIAG(RHMIN,RHOPT,RHMAX,8)
          GO TO 30
        ELSE IF (DIST.GT.RHOPT) THEN
          SHOOT = TRIAG(RHMIN,RHOPT,DIST,8)
          GO TO 30
        ELSE IF (DIST.GT.RHMIN) THEN
          SHOOT = UNFRM(RHMIN,DIST,8)
          GO TO 30
        ELSE
          GO TO 20
        END IF
      ELSE IF (DIST.GE.RTMAX) THEN
        SHOOT = TRIAG(0,RTOPT,RTMAX,8)
        GO TO 30
      ELSE IF (DIST.GE.RTOPT) THEN
        SHOOT = TRIAG(0,RTOPT,DIST,8)
        GO TO 30
      ELSE
        SHOOT = UNFRM(0,DIST,8)
      END IF
C                *HEAT ENGAGEMENT*
20    IF (TAIL.EQ.1) THEN
        IF (DIST.GT.HTOPT) THEN
          SHOOT = TRIAG(0,HTOPT,DIST,8)
```

```
            GO TO 30
          ELSE
            SHOOT = UNFRM(0,DIST,8)
            GO TO 30
          END IF
        ELSE IF (DIST.GT.HHOPT) THEN
          SHOOT = TRIAG(0,HHOPT,DIST,8)
          GO TO 30
        ELSE
          SHOOT = UNFRM(0,DIST,8)
        END IF
C
30      DIST = DIST - SHOOT
        TIME = DIST/XSPD*60
C       ---------------------------------------------------
C         ***SCHEDULE ENGAGEMENT OR RECOMPUTATION AS REQUIRED***
C       ---------------------------------------------------
C        PRINT *,'NEXT TURN-PT TIME =',ATRIB(10),'INTERCEPT TIME='
C       1              ,TIME+TNOW
        IF (TIME+TNOW .LE. ATRIB(10)) THEN
          CALL SCHDL(7,TIME,ATRIB)
        ELSE
C           *** UPDATE INTERCEPTOR POSITION ***
          SPD = FTRSPD/60
          TIME1 = ATRIB(10) - TNOW + .1
          HDG = (2.5 * PI) - ((FTR(7)) / CONVERT)
          FTR(5) = FTRX + (SPD * TIME1 * COS(HDG))
          FTR(6) = FTRY + (SPD * TIME1 * SIN(HDG))
        END IF
C
C         ***SET TGT ATTRIB TO SHOW INTERCEPT IN PROGRESS***
C
        ATRIB(13) = 2
        ATRIB(8) = TNOW
C
C         ***REFILE FIGHTER INTO PAIRED QUEUE***
C
        FTR(12) = TIME
        FTR(8) = TNOW
        CALL FILEM(5,FTR)
C
C

C        PRINT *,'INTERCEPT HDG=',FTR(7),' TIME TO INTERCEPT=',TIME
C        PRINT *,'LEAVING INTERCEPT'
        RETURN
        END
C
C         ============================================================
C         ============================================================
C
        SUBROUTINE TURN_PT
C
```

```
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,X,Y,DIST
     2,ANGLE,TRACK,A(20),PI,AITYPE,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT
     3,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS,I,J,ROUTE,TURNPT
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
      PARAMETER (PI = 3.14159265)
C
C       THIS ROUTINE CHANGES THE DIRECTION THE HOSTILE A/C IS FLYING
C       AT THE PENETRATION ROUTE TURN POINTS AND CALCULATES THE TIME
C       REQUIRED UNTIL THE NEXT TURNPOINT.
C
      I = 1
      J = 1
      ROUTE = ATRIB(7)
      TURNPT = ATRIB(15)
C       *** DETERMINE THE DISTANCE TO THE NEXT TURNPOINT ***
C
10    IF (ROUTECOORD(I,1).EQ.ROUTE) THEN
20      IF (J.EQ.TURNPT) THEN
          ATRIB(5) = ROUTECOORD(I+J-1,2)
          ATRIB(6) = ROUTECOORD(I+J-1,3)
          X = ROUTECOORD(I+J,2) - ATRIB(5)
          Y = ROUTECOORD(I+J,3) - ATRIB(6)
          DIST = SQRT((X**2)+(Y**2))
          GO TO 11
        ELSE
          J = J + 1
          GO TO 20
        END IF
      ELSE
        I = I + 1
        GO TO 10
      END IF
```

```
C
C        *** UPDATE ATRIBS (NEXT TURNPT. TIME TO NEXT TURNPT) ***
C
11    ATRIB(12) = (DIST/ATRIB(3))*60
      ATRIB(15) = ATRIB(15) + 1
      ATRIB(8) = TNOW
      ATRIB(10) = ATRIB(12) + ATRIB 8)
C
C      PRINT *,'                        TNOW=',TNOW
C      PRINT *,'DIST =',DIST,'ATRIB(5) =',ATRIB(5),'ATRIB(6) =',
C     1          ATRIB(6)
C      PRINT *,'ATRIB(12) =',ATRIB(12),'ATRIB(10)=',ATRIB(10),
C     1          'NEXT TURN PT =',ATRIB(15)
C
C        *** DETERMINE NEW HEADING ***
C
      ANGLE = (ACOS(X/DIST))*(180/PI)
C
      IF (X.GE.0) THEN
        GO TO 15
      ELSE
        GO TO 25
      END IF
C
15    IF (Y.GE.0) THEN
        ATRIB(16) = 90 - ANGLE
      ELSE
        ATRIB(16) = 90 + ANGLE
      END IF
      GO TO 35
C
25    IF (Y.GE.0) THEN
        ATRIB(16) = 450 - ANGLE
      ELSE
        ATRIB(16) = 90 + ANGLE
      END IF
C
C35    PRINT *,'NEW HEADING =',ATRIB(16)
C
C        *** UPDATE THE ENTITY IN THE OTHER 'WAITING' FILE ***
C
C                  DETERMINE WHICH FILE TO SEARCH
C
35      TRACK = ATRIB(11)
C      PRINT *,'PAIRED INDICATOR --- ATRIB(13)=',ATRIB(13)
      IF (ATRIB(13).EQ.2) THEN
        GO TO 30
      ELSE
        GO TO 40
      END IF
C
C       PULL ENTITY FROM FILE, RESET ATRIBS,AND RETURN TO FILE
C
```

```
C30     PRINT *,'SEARCHING PAIRED FILE ---QUEUE 2'
30       NRANK = NFIND(1,2,11,0,TRACK,0,0)
C       PRINT *,'TRYING TO REMOVE ENTRY #',NRANK
      CALL RMOVE(NRANK,2,A)
      DO 55 I=1,16
        A(I) = ATRIB(I)
55    CONTINUE
      CALL FILEM(2,A)
C
C        *** SCHEDULING INTERCEPT RECOMPUTATION ***
C       PRINT *,'INTERCEPT RE-COMPUTE REQUIRED'
      CALL SCHDL(8,.1,ATRIB)
C
      GO TO 60
C
C40     PRINT *,'SEARCHING UNPAIRED FILE ---QUEUE 1'
40       NRANK = NFIND(1,1,11,0,TRACK,0,0)
C       PRINT *,'TRYING TO REMOVE ENTRY #',NRANK
C        *** IF ENTITY NOT IN FILE, SEARCH OTHER FILE ***
      IF (NRANK .EQ. 0) THEN
        ATRIB(13) = 2
        GO TO 30
      END IF
      CALL RMOVE(NRANK,1,A)
      DO 45 I=1,16
        A(I) = ATRIB(I)
45    CONTINUE
      CALL FILEM(1,A)
C
C60     PRINT *,'LEAVING TURN_PT'
60       RETURN
      END

C
C        ==========================================================
C        ==========================================================
C
      SUBROUTINE RADAR_RANGE
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
```

```
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,
     2P_PEAK,FREQ,PRF,GAIN,SIG_NOISE,THETA_EL,THETA_AZ,TAU,RPM,
     3NOISE_FIG,EFFIC,SIGMA,LOSS,P_AVE,LAMDA,A_E,PI,K,T,C,N,BAND,
     4HOSTYPE,TYPE,RMAX(3),AITYPE,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT
     5,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS,I,J
C
      PARAMETER (PI=3.14159265,K=1.38E-23,T=290,C=2.9979E8)
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C       PRINT *,'CALLING RADAR_RANGE'
      HOSTYPE = ATRIB(2) -20
C         ///////////////////////////////////////////////////////////////
C                 DETERMINE RADAR MAX RANGE
C         ///////////////////////////////////////////////////////////////
C
      DO 10 I = 1,NUMTYPE
        P_PEAK = RADSPECS(I,2)
        FREQ = RADSPECS(I,3)
        PRF = RADSPECS (I,4)
        THETA_EL = RADSPECS(I,7)
        THETA_AZ = RADSPECS(I,8)
        TAU = RADSPECS(I,9)
        RPM = RADSPECS(I,10)
        EFFIC = RADSPECS(I,12)
        LOSS = RADSPECS(I,13)
        GAIN = 10**(RADSPECS(I,5)/10)
        SIG_NOISE = 10**(RADSPECS(I,6)/10)
        NOISE_FIG = 10**(RADSPECS(I,11)/10)
        SIGMA = HOSSPECS(HOSTYPE,5)
C
        P_AVE = P_PEAK*TAU*PRF
        LAMDA = C/FREQ
        A_E = (GAIN*(LAMDA**2))/(4*PI)
        N = (THETA_AZ*PRF)/(6*RPM)
        BAND = 1/TAU
C
        RMAX(I) = ((P_AVE*GAIN*A_E*SIGMA*N*EFFIC)/
     1   ((4*PI)**2*K*T*NOISE_FIG*BAND*TAU*PRF*SIG_NOISE*LOSS))
     2        **.25
C
C       *** CONVERT RADAR RANGE FROM METERS TO NAUTICAL MILES ***
        RMAX(I) = RMAX(I)/1852
C       PRINT *,'MAX RADAR RANGE IS',RMAX(I)
10    CONTINUE
C
C         ///////////////////////////////////////////////////////////////
C           DETERMINE RADAR HORIZON AND RADAR DETECTION RANGE
```

```
C       ////////////////////////////////////////////////////////
C
C        PRINT *,'RADAR DETECTION ARRAY:'
        DO 20 J = 1,NUMRADAR
          TYPE = RADCOORD(J,1)
          RADAR(J,1) = J
          RADAR(J,2) = TYPE
          RADAR(J,3) = 1.42*(SQRT(ATRIB(4))+SQRT(REAL(RADCOORD(J,4))))
          RADAR(J,4) = RMAX(TYPE)
          RADAR(J,5) = MIN(RADAR(J,3),RADAR(J,4))
C         PRINT *,(RADAR(J,L),L=1,5)
20      CONTINUE
C
C        PRINT *,'LEAVING RADAR_RANGE'
        RETURN
        END
C
C         ============================================================
C         ============================================================
C
        SUBROUTINE RADAR_DETECT
C
        DIMENSION NSET(150000)
        INCLUDE 'PARAM.INC'
C
        COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
       1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
       2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
        COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
       1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
        COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
        COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
       1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
        REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
       1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,
       2X,Y,TIME,RANGE(15),RADX,RADY,HDG,PI,TURNPT,X1,Y1,DIST,TIMENEXT,
       3ANGLE,HDG1,AITYPE,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT
       4,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
        INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
       1ROUTECOORD(100,5),TURNS,I,J,POINT,ROUTE
C
        COMMON QSET(150000)
        EQUIVALENCE (NSET(1),QSET(1))
        PARAMETER (PI = 3.14159265)
C
C         THIS SUBROUTINE DETERMINES THE TIME AT WHICH THE HOSTILE
C         AIRCRAFT ENTERS INTO THE DETECTION RANGE OF ANY OF THE RADARS
C         IN THE SCENARIO.  THIS IS DONE BY FIRST CALLING SUBROUTINE
```

```
C        RADAR_RANGE WHICH DETERMINES THE RANGE FOR DETECTION AND THEN
C        COMPARING THIS RANGE TO THE PRESENT POSITION OF THE AIRCRAFT.
C        IF NOT WITHIN RANGE, THE SUBROUTINE INCREMENTS THE POSITION OF
C        THE HOSTILE IN ONE MINUTE INCREMENTS UNTIL WITHIN RANGE.  IF
C        THE DETECTION RANGE OCCURS AFTER ONE OR MORE OF THE ROUTE
C        TURNPOINTS, THE ATRIBUTES OF THE AIRCRAFT ARE UPDATED AS
C        NEEDED.  UPON DETERMINATION OF THE RADAR DETECTION POSITION,
C        ATRIB(12) IS UPDATED WITH THE TIME UNTIL DETECTION WILL OCCUR.
C
      TURNPT = ATRIB(15)
      SPD = (ATRIB(3))/60
      HDG = ATRIB(16)*PI/180
      X = ATRIB(5)
      Y = ATRIB(6)
      TIME = 0.0
      TIMENEXT = 0.0
      POINT = 1
      ROUTE = ATRIB(7)
C
C        *** DETERMINE CURRENT RANGE TO RADARS ***
C
      CALL RADAR_RANGE
10    DO 20 I=1,NUMRADAR
        RADX = RADCOORD(I,2)
        RADY = RADCOORD(I,3)
        RANGE(I) = SQRT((RADX-X)**2 + (RADY-Y)**2)
        IF (RANGE(I).LE.RADAR(I,5)) THEN
          GO TO 100
        END IF
20    CONTINUE
C
C        *** NOT WITHIN RANGE --- INCREMENT POSITION ***
C
      TIME = TIME + 1
      HDG1 = (2.5*PI) - HDG
      X = X + (SPD*COS(HDG1))
      Y = Y + (SPD*SIN(HDG1))
C
C      PRINT *,'X=',X,' Y=',Y,' HDG=',ATRIB(16)
C        *** DETERMINE NEXT TURNPT COORDS ***
C
      I = 1
      J = 1
30    IF (ROUTECOORD(I,1).EQ.ROUTE) THEN
40      IF (J.EQ.TURNPT) THEN
          X1 = ROUTECOORD(I+J,2)
          Y1 = ROUTECOORD(I+J,3)
        ELSE
          J = J + 1
          GO TO 40
        END IF
      ELSE
        I = I + 1
```

```
          GO TO 30
        END IF
C
C         *** CHECK IF PAST TURNPT ***
C
        IF (ATRIB(16).GT.180) THEN
          IF (X.GT.X1) THEN
            GO TO 10
          ELSE
C         *** RESET TO TURNPT ***
            DIST = SQRT((ATRIB(5)-X1)**2+(ATRIB(6)-Y1)**2)
            TIME = DIST/SPD
            ATRIB(5) = X1
            ATRIB(6) = Y1
            ATRIB(15) = TURNPT+1
C         *** RESET HEADING ***
            X1 = ROUTECOORD(I+J+1,2) - X1
            Y1 = ROUTECOORD(I+J+1,3) - Y1
            DIST = SQRT((X1**2) + (Y1**2))
            ANGLE = (ACOS(X1/DIST))*(180/PI)
C           PRINT *,'I+J+1=',I+J+1
C         *** CONVERT ANGLE TO HEADING ***
            IF (X1.GE.0) THEN
              IF (Y1.GE.0) THEN
                HDG = 90 - ANGLE
                ATRIB(16) = HDG
              ELSE
                HDG = 90 + ANGLE
                ATRIB(16) = HDG
              END IF
            ELSE
              IF (Y1.GE.0) THEN
                HDG = 450 - ANGLE
                ATRIB(16) = HDG
              ELSE
                HDG = 90 + ANGLE
                ATRIB(16) = HDG
              END IF
            END IF
          END IF
        END IF
C
C        PRINT *,'ANGLE =',ANGLE,' NEW HDG =',HD
        GO TO 10
C
C         *** SET DETECTION DELAY AND FINISH ***
C
100      ATRIB(12) = TIME
C
C        PRINT *,'DETECTION DELAY =',ATRIB(12)
C        PRINT *,'LEAVING RADAR_DETECT'
        RETURN
        END
```

```
C
C     ===============================================================
C     ===============================================================
C
      SUBROUTINE OTPUT
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,TYPE,AVE,MAX,STDDEV,RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT
     3,HHMIN,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),
     1ROUTECOORD(100,5),TURNS,RADAR1,RADAR2,RADAR3,I
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C       THIS ROUTINE CREATES AND FILLS THE OUTPUT DATA FILE FOR
C       LATER ANALYSIS.
C
      OPEN (18,FILE='OUTPUT.DAT',STATUS='OLD')
C
      AVE = FFAVG(5)
      MAX = FFMAX(5)
      STDDEV = FFSTD(5)
C
      WRITE (18,*) (MODEL(I),I=1,5),AVE,MAX,STDDEV,XX(2),XX(3),XX(4)
C
      RETURN
      END
C
C     ===============================================================
C     ===============================================================
C
      SUBROUTINE CAP
C
      DIMENSION NSET(150000)
```

```
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX,RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,FTR(20),TRACK
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),CAPP,
     1ROUTECOORD(100,5),RANK
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
C
C       THIS ROUTINE PLACES THE INTERCEPTOR BACK AT HIS CAP
C       LOCATION IF HE WAS NOT PAIRED WHILE RETURNING TO CAP.
C       THIS ROUTINE IS CALLED ONLY AFTER AN INTERCEPTOR HAS
C       KILLED THE HOSTILE IT WAS PAIRED AGAINST, OR THAT HOSTILE
C       IS NO LONGER A THREAT BECAUSE IT WAS EXITING FROM THE
C       SYSTEM.
C
C       **** IF CURRENTLY PAIRED, DO NOTHING ****
C
      TRACK = ATRIB(16)
C      PRINT *,'TRACK=',TRACK
      RANK = NFIND(1,4,16,0,TRACK,0)
C      PRINT *,'RANK=',RANK
      IF (RANK.GT.0) THEN
        CALL RMOVE(RANK,4,FTR)
      ELSE
        RANK = NFIND(1,5,16,0,TRACK,0)
          IF (RANK.GT.0) THEN
            CALL RMOVE(RANK,5,FTR)
          ELSE
            CALL SCHDL(6,.1,ATRIB)
            RETURN
          END IF
      END IF
C
      IF (FTR(14).EQ.1) THEN
        CALL FILEM(5,FTR)
        RETURN
C
```

```
C         **** IF NOT PAIRED, PUT BACK ON CAP ***
C
      ELSE
        CAPP = INT(FTR(13))
        FTR(5) = CAPCOORD(CAPP,2)
        FTR(6) = CAPCOORD(CAPP,3)
        FTR(8) = TNOW
        FTR(3) = 0
        CALL FILEM(4,FTR)
      END IF
C
      RETURN
      END
C
C       ==============================================================
C       ==============================================================
C
      SUBROUTINE ENGAGE
C
      DIMENSION NSET(150000)
      INCLUDE 'PARAM.INC'
C
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
     1MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
     2SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
C
      COMMON/UCOM1/RADSPECS,AISPECS,HOSSPECS,NUMTYPE,NUMHOS,NUMCAP,
     1NUMROUTES,NUMRADAR,NUMAI,RADAR,AITYPE
C
      COMMON/UCOM2/MODEL,CAPCOORD,TURNS,RADCOORD,ROUTECOORD
C
      COMMON/UCOM3/RHMAX.RHOPT,RHMIN,RTMAX,RTOPT,HHMAX,HHOPT,HHMIN
     1,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK
C
      REAL RADSPECS(3,15),AISPECS(5,10),HOSSPECS(5,10),RADAR(15,5)
     1,NUMTYPE,NUMHOS,NUMCAP,NUMRADAR,NUMROUTES,NUMAI,AITYPE
     2,TRACK,FTR(20),HDG,HDG1,PI,SPD,TIME,RHMAX,RHOPT,RHMIN,RTMAX
     3,RTOPT,HHMAX,HHOPT,HHMIN,HTMAX,HTOPT,RHPK,RTPK,HHPK,HTPK,PK(2)
C
      INTEGER MODEL(5),CAPCOORD(15,3),RADCOORD(15,4),CAP,
     1ROUTECOORD(100,5),TURNS,RANK,HEAT,KILL,PAIR,WD
C
      COMMON QSET(150000)
      EQUIVALENCE (NSET(1),QSET(1))
      PARAMETER (PI = 3.14159265)
C
C       THIS ROUTINE CHECK THE ENGAGEMENTS PARAMETERS TO DETERMINE
C       IF THE HOSTILE AIRCRAFT HAS BEEN NEUTRALIZED.  IT ALSO CHECKS
C       THE AMOUNT OF TIME AND MISSILES THAT THE INTERCEPTOR HAS
C       REMAINING.  IF NECESSARY, THE INTERCEPTOR IS PUT BACK INTO
C       THE NETWORK TO 'LAND AND REFUEL/RE-ARM'.  OTHERWISE, THE
C       POSITION OF THE INTERCEPTOR IS UPDATED, AND RE-PAIRED OR SENT
C       BACK TO CAP IF NO OTHER HOSTILE AIRCRAFT NEED TO BE
```

```
C        INTERCEPTED.
C
C        *** GET THE PAIRED INTERCEPTOR ***
C
      TRACK = ATRIB(11)
      RANK = NFIND(1,5,11,0,TRACK,0)
      CALL RMOVE(RANK,5,FTR)
C
C        *** GET THE PAIRED HOSTILE ***
      RANK = NFIND (1,2,11,0,TRACK,0)
      CALL RMOVE(RANK,2,ATRIB)
C        -------------------------------------------
C        *** CHECK THE RESULTS OF THE ENGAGEMENT ***
C        -------------------------------------------
C           **CHECK FOR ASPECT ANGLE**
      ASPECT = ABS(ATRIB(16) - FTR(7))
      IF ((ASPECT .LE. 60) .OR. (ASPECT .GE. 300)) THEN
C        *TAIL ASPECT*
        TAIL = 1
      ELSE
C        *HEAD ASPECT*
        TAIL = 0
      END IF
C          **CHECK FOR RADAR/HEAT ENGAGEMENT**
      IF (FTR(9) .EQ. 0) THEN
        GO TO 20
      ELSE IF ((TAIL.EQ.1).AND.(DIST.LE.HTMAX).AND.(FTR(10).GT.0))
     1                    THEN
        GO TO 20
      ELSE IF ((DIST.LE.HHMAX).AND.(FTR(10).GT.0).AND.(DRAND(9).GT.
     1              (.5))) THEN
C                *RADAR ENGAGEMENT*
      ELSE IF (TAIL.EQ.0) THEN
        IF (DIST.GE.RHMAX) THEN
          HEAT = 0
          GO TO 30
        ELSE IF (DIST.GT.RHOPT) THEN
          HEAT = 0
          GO TO 30
        ELSE IF (DIST.GT.RHMIN) THEN
          HEAT = 0
          GO TO 30
        ELSE
          GO TO 20
        END IF
      ELSE IF (DIST.GE.RTMAX) THEN
        HEAT = 0
        GO TO 30
      ELSE IF (DIST.GE.RTOPT) THEN
        HEAT = 0
        GO TO 30
      ELSE
        HEAT = 0
```

```
      END IF
C                 *HEAT ENGAGEMENT*
20    IF (TAIL.EQ.1) THEN
        IF (DIST.GT.HTOPT) THEN
          HEAT = 1
          GO TO 30
        ELSE
          HEAT = 1
          GO TO 30
        END IF
      ELSE IF (DIST.GT.HHOPT) THEN
        HEAT = 1
        GO TO 30
      ELSE
        HEAT = 1
      END IF
C
30    DO 40 I = 1,2
        PK(I) = DRAND(9)
C       ** HEAD-ON, RADAR **
        IF ((TAIL.EQ.0).AND.(HEAT.EQ.0)) THEN
          IF (PK(I).LE.RHPK) THEN
            KILL = 1
          END IF
C       ** HEAD-ON, HEAT **
        ELSE IF ((TAIL.EQ.0).AND.(HEAT.EQ.1)) THEN
          IF (PK(I).LE.HHPK) THEN
            KILL = 1
          END IF
C       ** TAIL-ASPECT, RADAR **
        ELSE IF ((TAIL.EQ.1).AND.(HEAT.EQ.0)) THEN
          IF (PK(I).LE.RTPK) THEN
            KILL = 1
          END IF
C       ** TAIL-ASPECT, HEAT **
        ELSE IF ((TAIL.EQ.1).AND.(HEAT.EQ.1)) THEN
          IF (PK(I).LE.HTPK) THEN
            KILL = 1
          END IF
C       ** NO KILL **
        ELSE
          KILL = 0
        END IF
C
C       ** REDUCE HOSTILE FLIGHT SIZE IF KILL OCCURS **
        IF (KILL.EQ.1) THEN
          ATRIB(9) = ATRIB(9) - 1
        END IF
C
40    CONTINUE
C
C       --------------------------------------------------
C       *** ANOTHER INTERCEPT/ENGAGEMENT NEEDED?? ***
```

```
C        ------------------------------------------------
C          **ENTIRE FLIGHT KILLED?**
      IF (ATRIB(9).LE.0) THEN
        ATRIB(13) = 3
C       PRINT *,'ENTIRE HOSTILE FLIGHT KILLED -- LEAVING NETWORK'
        PAIR = 0
        XX(3) = XX(3) + 1
        GO TO 90
C          **HOSTILE FLIGHT NO LONGER A THREAT?**
      ELSE IF (ATRIB(5).GT.400) THEN
        ATRIB(13) = 3
C       PRINT *,'HOSTILE FLIGHT GOING HOME -- PAST FEBA'
        PAIR = 0
        GO TO 90
C          **NEW INTERCEPT/ENGAGEMENT REQUIRED**
      ELSE
        CALL SCHDL(8,0,ATRIB)
C       PRINT *,'HOSTILE FLIGHT STILL FLYING -- REATTACKING'
        PAIR = 1
        GO TO 100
      END IF
C
C        *** FREE THE CONTROLLER RESOURCE ***
90    WD = INT(FTR(15))
      CALL FREE(WD,1)
      FTR(14) = 0
C
C        *** UPDATE THE INTERCEPTOR POSITION ***
100   HDG = FTR(7)*PI/180
      HDG1 = (2.5*PI) - HDG
      TIME = TNOW - FTR(8)
      SPD = (FTR(3))/60
      FTR(5) = FTR(5) + (SPD*COS(HDG1)*TIME)
      FTR(6) = FTR(6) + (SPD*SIN(HDG1)*TIME)
      FTR(8) = TNOW
C
C        *** CHECK WHICH FILE TO PUT INTERCEPTOR INTO ***
      IF (PAIR .EQ. 0) THEN
        CALL FILEM(4,FTR)
C
C        *** START HEADING BACK TOWARDS CAP POINT ***
        CAP = INT(FTR(13))
        X = CAPCOORD(CAP,2) - FTR(5)
        Y = CAPCOORD(CAP,3) - FTR(6)
        DIST = SQRT((X**2)+(Y**2))
        FTR(12) = (DIST/FTR(3)) * 60
C
C        *** DETERMINE HEADING BACK TO CAP ***
        ANGLE = (ACOS(X/DIST))*(180/PI)
C
        IF (X.GE.0) THEN
          GO TO 101
        ELSE
```

```
            GO TO 102
          END IF
C
101       IF (Y.GE.0) THEN
            FTR(7) = 90 - ANGLE
          ELSE
            FTR(7) = 90 + ANGLE
          END IF
          GO TO 103
C
102       IF (Y.GE.0) THEN
            FTR(7) = 450 - ANGLE
          ELSE
            FTR(7) = 90 + ANGLE
          END IF
C
C         *** SCHEDULE ARRIVAL BACK AT CAP ***
103       CALL SCHDL(6,FTR(12),FTR)
C
        ELSE
          CALL FILEM(5,FTR)
        END IF
C
110     CALL FILEM(2,ATRIB)
C        PRINT *,'END ENGAGEMENT POSITION -- XCOORD=',FTR(5)
C        PRINT *,'                            YCOORD=',FTR(6)
C
C        PRINT *,'LEAVING ENGAGE'
        RETURN
        END
C
```

Appendix D. Output Analysis

C-Max Results

OBS	AWAC	FACP	CNTRL	ATK	TYPE	AVE	CMAX	STDDEV	HOSTILE	KILL	PAIRS
1	1	1	1	1	1	19.1361	51	7.11358	5400	5123	5153
2	1	1	1	1	1	19.5013	49	7.21047	5387	5069	5109
3	1	1	1	0	1	21.6515	55	7.91965	5400	5121	5159
4	1	1	1	0	1	21.3369	55	7.76135	5387	5080	5123
5	1	1	0	1	1	18.2468	28	5.32881	5400	5086	5111
6	1	1	0	1	1	18.4599	28	5.33405	5387	5058	5084
7	1	1	0	0	1	20.1950	28	5.25450	5400	5098	5126
8	1	1	0	0	1	19.9275	28	5.40769	5387	5043	5071
9	1	0	1	1	1	19.3045	47	6.94798	5400	5115	5150
10	1	0	1	1	1	19.4920	47	6.81785	5387	5072	5109
11	1	0	1	0	1	21.2508	54	7.85117	5400	5116	5155
12	1	0	1	0	1	21.0767	55	7.94438	5387	5078	5118
13	1	0	0	1	1	17.9588	28	5.05214	5400	5093	5119
14	1	0	0	1	1	17.9926	28	5.02206	5387	5033	5061
15	1	0	0	0	1	20.0235	28	5.26170	5400	5066	5094
16	1	0	0	0	1	19.7534	28	5.06580	5387	5042	5067
17	0	1	1	1	1	19.3844	46	6.92780	5400	5117	5151
18	0	1	1	1	1	19.1832	44	7.22769	5387	5072	5112
19	0	1	1	0	1	21.4014	47	7.47968	5400	5124	5161
20	0	1	1	0	1	21.3349	47	7.48716	5387	5079	5119
21	0	1	0	1	1	17.5065	24	4.31904	5400	5001	5025
22	0	1	0	1	1	17.5927	24	4.05806	5387	4978	5001
23	0	1	0	0	1	19.2243	24	4.35915	5400	5030	5054
24	0	1	0	0	1	19.2990	24	4.34835	5387	4979	5003
25	0	0	1	1	1	18.8464	45	6.75684	5400	5108	5141
26	0	0	1	1	1	19.0775	41	6.60291	5387	5066	5104
27	0	0	1	0	1	21.3589	47	7.15037	5400	5091	5126
28	0	0	1	0	1	21.4383	47	7.02026	5387	5047	5076
29	0	0	0	1	1	17.5923	24	4.08904	5400	4983	5005
30	0	0	0	1	1	17.3586	24	4.10800	5387	4926	4950
31	0	0	0	0	1	18.5505	24	4.13121	5400	4892	4915
32	0	0	0	0	1	18.4778	24	4.10950	5387	4793	4817

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
AWAC	2	0 1
FACP	2	0 1
CNTRL	2	0 1
ATK	2	0 1

ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: CMAX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	15	4395.96875000	293.06458333
ERROR	16	12.50000000	0.78125000
CORRECTED TOTAL	31	4408.46875000	
MODEL F =	375.12		PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	CMAX MEAN
0.997165	2.3709	0.88388348	37.28125000

SOURCE	DF	ANOVA SS	F VALUE	PR > F
AWAC	1	205.03125000	262.44	0.0001
FACP	1	3.78125000	4.84	0.0428
AWAC*FACP	1	0.28125000	0.36	0.5569
CNTRL	1	4072.53125000	5212.84	0.0001
AWAC*CNTRL	1	9.03125000	11.56	0.0037
FACP*CNTRL	1	3.78125000	4.84	0.0428
AWAC*FACP*CNTRL	1	0.28125000	0.36	0.5569
ATK	1	42.78125000	54.76	0.0001
AWAC*ATK	1	5.28125000	6.76	0.0193
FACP*ATK	1	2.53125000	3.24	0.0907
AWAC*FACP*ATK	1	0.03125000	0.04	0.8440
CNTRL*ATK	1	42.78125000	54.76	0.0001
AWAC*CNTRL*ATK	1	5.28125000	6.76	0.0193
FACP*CNTRL*ATK	1	2.53125000	3.24	0.0907
AWAC*FACP*CNTRL*ATK	1	0.03125000	0.04	0.8440

ANALYSIS OF VARIANCE PROCEDURE
T TESTS (LSD) FOR VARIABLE: CMAX

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=16 MSE=0.78125
CRITICAL VALUE OF T=2.11991
LEAST SIGNIFICANT DIFFERENCE=.66247

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	AWAC
A	39.8125	16	1
B	34.7500	16	0

T GROUPING	MEAN	N	FACP
A	37.6250	16	1
B	36.9375	16	0

ANALYSIS OF VARIANCE PROCEDURE
MEANS

AWAC	FACP	N	CMAX
0	0	8	34.5000000
0	1	8	35.0000000
1	0	8	39.3750000
1	1	8	40.2500000

ANALYSIS OF VARIANCE PROCEDURE
T TESTS (LSD) FOR VARIABLE: CMAX

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=16 MSE=0.78125
CRITICAL VALUE OF T=2.11991
LEAST SIGNIFICANT DIFFERENCE=.66247

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	CNTRL
A	48.5625	16	1
B	26.0000	16	0

ANALYSIS OF VARIANCE PROCEDURE

MEANS

AWAC	CNTRL	N	CMAX
0	0	8	24.0000000
0	1	8	45.5000000
1	0	8	28.0000000
1	1	8	51.6250000

FACP	CNTRL	N	CMAX
0	0	8	26.0000000
0	1	8	47.8750000
1	0	8	26.0000000
1	1	8	49.2500000

AWAC	FACP	CNTRL	N	CMAX
0	0	0	4	24.0000000
0	0	1	4	45.0000000
0	1	0	4	24.0000000
0	1	1	4	46.0000000
1	0	0	4	28.0000000
1	0	1	4	50.7500000
1	1	0	4	28.0000000
1	1	1	4	52.5000000

ANALYSIS OF VARIANCE PROCEDURE
T TESTS (LSD) FOR VARIABLE: CMAX

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=16 MSE=0.78125
CRITICAL VALUE OF T=2.11991
LEAST SIGNIFICANT DIFFERENCE=.66247

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	ATK
A	38.4375	16	0
B	36.1250	16	1

ANALYSIS OF VARIANCE PROCEDURE

MEANS

AWAC	ATK	N	CMAX
0	0	8	35.5000000
0	1	8	34.0000000
1	0	8	41.3750000
1	1	8	38.2500000

FACP	ATK	N	CMAX
0	0	8	38.3750000
0	1	8	35.5000000
1	0	8	38.5000000
1	1	8	36.7500000

AWAC	FACP	ATK	N	CMAX
0	0	0	4	35.5000000
0	0	1	4	33.5000000
0	1	0	4	35.5000000
0	1	1	4	34.5000000
1	0	0	4	41.2500000
1	0	1	4	37.5000000
1	1	0	4	41.5000000
1	1	1	4	39.0000000

CNTRL	ATK	N	CMAX
0	0	8	26.0000000
0	1	8	26.0000000
1	0	8	50.8750000
1	1	8	46.2500000

AWAC	CNTRL	ATK	N	CMAX
0	0	0	4	24.0000000
0	0	1	4	24.0000000
0	1	0	4	47.0000000
0	1	1	4	44.0000000
1	0	0	4	28.0000000
1	0	1	4	28.0000000
1	1	0	4	54.7500000
1	1	1	4	48.5000000

ANALYSIS OF VARIANCE PROCEDURE

MEANS

FACP	CNTRL	ATK	N	CMAX
0	0	0	4	26.0000000
0	0	1	4	26.0000000
0	1	0	4	50.7500000
0	1	1	4	45.0000000
1	0	0	4	26.0000000
1	0	1	4	26.0000000
1	1	0	4	51.0000000
1	1	1	4	47.5000000

AWAC	FACP	CNTRL	ATK	N	CMAX
0	0	0	0	2	24.0000000
0	0	0	1	2	24.0000000
0	0	1	0	2	47.0000000
0	0	1	1	2	43.0000000
0	1	0	0	2	24.0000000
0	1	0	1	2	24.0000000
0	1	1	0	2	47.0000000
0	1	1	1	2	45.0000000
1	0	0	0	2	28.0000000
1	0	0	1	2	28.0000000
1	0	1	0	2	54.5000000
1	0	1	1	2	47.0000000
1	1	0	0	2	28.0000000
1	1	0	1	2	28.0000000
1	1	1	0	2	55.0000000
1	1	1	1	2	50.0000000

C-Min Results

OBS	AWAC	FACP	CNTRL	ATK	TYPE	AVE	CMIN	STDDEV	HOSTILE	KILL	PAIRS
1	1	0	0	0	0	17.5787	21	3.6338	5400	4891	4912
2	1	0	0	0	0	17.4165	21	3.6398	5387	4822	4843
3	1	0	0	0	0	17.6410	21	3.7002	5385	4904	4925
4	1	1	1	1	0	18.1445	40	6.7315	5400	5121	5151
5	1	1	1	1	0	18.1467	41	6.7018	5387	5071	5104
6	1	1	1	1	0	18.3151	41	6.6931	5385	5121	5154
7	1	1	1	0	0	19.5035	41	7.1518	5400	5119	5154
8	1	1	1	0	0	19.6079	41	7.4500	5387	5082	5113
9	1	1	1	0	0	19.8611	41	7.1265	5385	5120	5153
10	1	1	0	1	0	16.5963	21	3.5952	5400	4919	4939
11	1	1	0	1	0	16.6096	21	3.8542	5387	4820	4841
12	1	1	0	1	0	16.8214	21	3.6737	5385	4940	4958
13	1	1	0	0	0	17.7836	21	3.7003	5400	4933	4954
14	1	1	0	0	0	17.7633	21	3.8527	5387	4919	4940
15	1	1	0	0	0	17.8781	21	3.7470	5385	4959	4980
16	1	0	1	0	0	19.7473	41	6.8968	5400	5117	5139
17	1	0	1	0	0	19.6129	41	7.0889	5387	5074	5109
18	1	0	1	0	0	19.5361	41	6.8146	5385	5132	5168
19	1	0	0	1	0	16.2598	21	3.7090	5400	4903	4920
20	1	0	0	1	0	16.1412	21	3.7843	5387	4866	4887
21	1	0	0	1	0	16.3630	21	3.8041	5385	4924	4945
22	0	1	1	1	0	18.0211	34	6.3507	5400	5105	5136
23	0	1	1	1	0	17.9743	34	6.1310	5387	5051	5083
24	0	1	1	1	0	18.2269	34	6.1425	5385	5098	5125
25	1	0	1	1	0	18.1691	41	6.1162	5400	5113	5142
26	1	0	1	1	0	18.3702	44	6.6550	5387	5070	5095
27	1	0	1	1	0	18.1655	41	6.3915	5385	5118	5153
28	0	1	1	0	0	19.4944	37	6.6292	5400	5107	5135
29	0	1	1	0	0	19.2773	37	6.9040	5387	5065	5102
30	0	1	1	0	0	19.6223	37	6.4916	5385	5113	5146
31	0	1	0	1	0	14.7077	18	2.8013	5400	4677	4695
32	0	1	0	1	0	14.7892	18	2.8564	5387	4608	4624
33	0	1	0	1	0	14.6283	18	2.8945	5385	4647	4665
34	0	1	0	0	0	16.0383	18	2.9543	5400	4657	4675
35	0	1	0	0	0	15.9235	18	3.1365	5387	4654	4672
36	0	1	0	0	0	16.1232	18	3.0507	5385	4650	4668
37	0	0	1	1	0	18.1168	37	6.4034	5400	5093	5122
38	0	0	1	1	0	18.1906	37	6.1826	5387	5037	5066
39	0	0	1	1	0	18.5883	37	6.0007	5385	5069	5100
40	0	0	1	0	0	19.3705	37	6.0828	5400	5025	5059
41	0	0	1	0	0	19.3131	37	6.3550	5387	5016	5049
42	0	0	1	0	0	19.3638	37	6.1743	5385	5066	5098

OBS	AWAC	FACP	CNTRL	ATK	TYPE	AVE	CMIN	STDDEV	HOSTILE	KILL	PAIRS
43	0	0	0	1	0	14.5423	18	2.9864	5400	4549	4567
44	0	0	0	1	0	14.4397	18	2.9341	5387	4528	4543
45	0	0	0	1	0	14.6172	18	2.9443	5385	4591	4609
46	0	0	0	0	0	15.3224	18	3.0466	5400	4387	4405
47	0	0	0	0	0	15.0663	18	3.1341	5387	4372	4390
48	0	0	0	0	0	15.1741	18	3.2000	5385	4403	4421

ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
AWAC	2	0 1
FACP	2	0 1
CNTRL	2	0 1
ATK	2	0 1

ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: CMIN

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	15	4649.81250000	309.98750000
ERROR	32	6.66666667	0.20833333
CORRECTED TOTAL	47	4656.47916667	

MODEL F = 1487.94 PR > F = 0.0

R-SQUARE	C.V.	ROOT MSE	CMIN MEAN
0.998568	1.5683	0.45643546	29.10416667

SOURCE	DF	ANOVA SS	F VALUE	PR > F
AWAC	1	188.02083333	902.50	0.0001
FACP	1	3.52083333	16.90	0.0003
AWAC*FACP	1	0.52083333	2.50	0.1237
CNTRL	1	4427.52083333	21252.10	0.0
AWAC*CNTRL	1	11.02083333	52.90	0.0001
FACP*CNTRL	1	3.52083333	16.90	0.0003
AWAC*FACP*CNTRL	1	0.52083333	2.50	0.1237
ATK	1	1.02083333	4.90	0.0341
AWAC*ATK	1	2.52083333	12.10	0.0015
FACP*ATK	1	3.52083333	16.90	0.0003
AWAC*FACP*ATK	1	0.52083333	2.50	0.1237
CNTRL*ATK	1	1.02083333	4.90	0.0341
AWAC*CNTRL*ATK	1	2.52083333	12.10	0.0015
FACP*CNTRL*ATK	1	3.52083333	16.90	0.0003
AWAC*FACP*CNTRL*ATK	1	0.52083333	2.50	0.1237

ANALYSIS OF VARIANCE PROCEDURE
T TESTS (LSD) FOR VARIABLE: CMIN

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=32 MSE=0.208333
CRITICAL VALUE OF T=2.03693
LEAST SIGNIFICANT DIFFERENCE=.26839

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	AWAC
A	31.0833	24	1
B	27.1250	24	0

T GROUPING	MEAN	N	FACP
A	29.3750	24	0
B	28.8333	24	1

ANALYSIS OF VARIANCE PROCEDURE

MEANS

AWAC	FACP	N	CMIN
0	0	12	27.5000000
0	1	12	26.7500000
1	0	12	31.2500000
1	1	12	30.9166667

ANALYSIS OF VARIANCE PROCEDURE
T TESTS (LSD) FOR VARIABLE: CMIN

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE.
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=32 MSE=0.208333
CRITICAL VALUE OF T=2.03693
LEAST SIGNIFICANT DIFFERENCE=.26839

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	CNTRL
A	38.7083	24	1
B	19.5000	24	0

ANALYSIS OF VARIANCE PROCEDURE
MEANS

AWAC	CNTRL	N	CMIN
0	0	12	18.0000000
0	1	12	36.2500000
1	0	12	21.0000000
1	1	12	41.1666667

FACP	CNTRL	N	CMIN
0	0	12	19.5000000
0	1	12	39.2500000
1	0	12	19.5000000
1	1	12	38.1666667

AWAC	FACP	CNTRL	N	CMIN
0	0	0	6	18.0000000
0	0	1	6	37.0000000
0	1	0	6	18.0000000
0	1	1	6	35.5000000
1	0	0	6	21.0000000
1	0	1	6	41.5000000
1	1	0	6	21.0000000
1	1	1	6	40.8333333

ANALYSIS OF VARIANCE PROCEDURE
T TESTS (LSD) FOR VARIABLE: CMIN

NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=32 MSE=0.208333
CRITICAL VALUE OF T=2.03693
LEAST SIGNIFICANT DIFFERENCE=.26839

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING	MEAN	N	ATK
A	29.2500	24	0
B	28.9583	24	1

ANALYSIS OF VARIANCE PROCEDURE

MEANS

AWAC	ATK	N	CMIN
0	0	12	27.5000000
0	1	12	26.7500000
1	0	12	31.0000000
1	1	12	31.1666667

FACP	ATK	N	CMIN
0	0	12	29.2500000
0	1	12	29.5000000
1	0	12	29.2500000
1	1	12	28.4166667

AWAC	FACP	ATK	N	CMIN
0	0	0	6	27.5000000
0	0	1	6	27.5000000
0	1	0	6	27.5000000
0	1	1	6	26.0000000
1	0	0	6	31.0000000
1	0	1	6	31.5000000
1	1	0	6	31.0000000
1	1	1	6	30.8333333

ANALYSIS OF VARIANCE PROCEDURE
MEANS

CNTRL	ATK	N	CMIN
0	0	12	19.5000000
0	1	12	19.5000000
1	0	12	39.0000000
1	1	12	38.4166667

AWAC	CNTRL	ATK	N	CMIN
0	0	0	6	18.0000000
0	0	1	6	18.0000000
0	1	0	6	37.0000000
0	1	1	6	35.5000000
1	0	0	6	21.0000000
1	0	1	6	21.0000000
1	1	0	6	41.0000000
1	1	1	6	41.3333333

FACP	CNTRL	ATK	N	CMIN
0	0	0	6	19.5000000
0	0	1	6	19.5000000
0	1	0	6	39.0000000
0	1	1	6	39.5000000
1	0	0	6	19.5000000
1	0	1	6	19.5000000
1	1	0	6	39.0000000
1	1	1	6	37.3333333

AWAC	FACP	CNTRL	ATK	N	CMIN
0	0	0	0	3	18.0000000
0	0	0	1	3	18.0000000
0	0	1	0	3	37.0000000
0	0	1	1	3	37.0000000
0	1	0	0	3	18.0000000
0	1	0	1	3	18.0000000
0	1	1	0	3	37.0000000
0	1	1	1	3	34.0000000
1	0	0	0	3	21.0000000
1	0	0	1	3	21.0000000
1	0	1	0	3	41.0000000
1	0	1	1	3	42.0000000
1	1	0	0	3	21.0000000
1	1	0	1	3	21.0000000
1	1	1	0	3	41.0000000
1	1	1	1	3	40.6666667

Power Calculations

The formula used for power determination is provided by Montgomery in his text, Design and Analysis of Experiments (Montgomery:101).

$$\Phi^2 = \frac{n D^2}{2 a \sigma^2}$$

where Φ = the dependent variable on the Operating Characteristic Curve
n = number of replications
D = the magnitude of the difference to be detected
a = the number of levels for the treatment (factor) variable
σ = the variance of the resulting treatment means

The following values were used for the calculation of :

	C-max	C-min
n	16	24
D	1	1
a	2	2
σ	.8839	.4564

These values resulted in being equal to 2.26 (C-max) and 5.37 (C-min). With this information and the Operating Characteristic Curves for the fixed effects model, (Montgomery:515), the power of the experiment was calculated to be approximately 85% for C-max and greater than 99% for C-min

Appendix E. Model User's Guide

The model presented in this thesis is a SLAM simulation model that requires little modification of the code to run several different scenarios. The FORTRAN code was written so that most of the scenario is driven through several user provided data files, and does not require the user to modify the executable code. The major portion of the simulation code is the FORTRAN main program entitled 'WD.FOR'. The SLAM network coding is entitled 'WD.DAT'. The user provided data files are: 'AI.DAT', 'CAPS.DAT', 'HOSSPECS.DAT', 'RADLOC.DAT', 'RADSPECS.DAT', 'ROUTES.DAT', and 'SCENARIO.DAT'. The user must also provide an empty file, 'OUTPUT.DAT', for the model to write results into.

During the initialization of each simulation run, the model reads the input data files as part of the INTLC subroutine call. Because the data read during this time is placed into FORTRAN COMMON, the data files must contain specific data in a specified order. A discussion concerning the data required and the format for these files is provided below.

AI.DAT. This file contains the performance specifications for the Airborne Interceptor aircraft. The format for this file is:

Line 1: Number of different Types of aircraft specified in this file. (Normally 2, C-max and C-min)

Lines 2 to (number of types + 1): Aircraft type performance specifications.

Field 1: Integer number specifying which type this line contains specs for.
Field 2: Maximum speed (knots)
Field 3: Minimum Speed (knots)
Field 4: Number of radar missiles
Field 5: Number of Infra-red missiles
Field 6: Not Used in final version of code.

Line (Number of types + 2): Radar missile specifications. (All ranges in Nautical Miles)
Field 1: Maximum front aspect engagement range
Field 2: Optimum front aspect engagement range
Field 3: Minimum front aspect engagement range
Field 4: Maximum rear aspect engagement range
Field 5: Optimum rear aspect engagement range
Field 6: Front aspect probability of kill
Field 7: Rear aspect probability of kill

Line (Number of types + 3): IR missile specifications. The format for this line is the same as for the radar missile.

CAPS.DAT. This file contains the grid coordinates for all combat air patrol (CAP) locations.

Line 1: Integer number of CAPS in the scenario

Lines 2 to (number of CAPS + 1):
Field 1: Integer CAP number
Field 2: X grid coordinate
Field 3: Y grid coordinate

HOSSPECS.DAT. HOStile aircraft SPECificationS data.

Line 1: Integer number of different hostile aircraft types included in the scenario.

Lines 2 to (number of types + 1):
Field 1: Integer type number
Field 2: Minimum speed (knots)
Field 3: Optimum speed (knots)
Field 4: Maximum speed (knots)
Field 5: Radar cross section (square meters)

RADLOC.DAT. RADar LOCations data.

Line 1: Integer number of radars in the scenario

Lines 2 to (number of radars + 1):

Field 1: Radar type (integer number, corresponds to the radar type used in RADSPECS.DAT)
Field 2: X grid coordinate
Field 3: Y grid coordinate

RADSPECS.DAT. RADar SPECificationS data.

Line 1: Integer number of different types of radars in the scenario.

Lines 2 to (number of radar types + 1):
- Field 1: Integer radar type
- Field 2: Radar Power (watts)
- Field 3: Radar Frequency (hertz)
- Field 4: Pulse Repetition Frequency (hertz)
- Field 5: Antenna Gain (dB)
- Field 6: Signal to Noise ratio (dB)
- Field 7: Antenna elevation beamwidth (degrees)
- Field 8: Antenna azimuth beamwidth (degrees)
- Field 9: Frequency Bandwidth (hertz)
- Field 10: Antenna rotation rate (rpm)
- Field 11: Radar Noise Figure (dB)
- Field 12: Antenna Efficiency Factor (number between 0 and 1)
- Field 13: Radar Loss Factor (dB)

ROUTES.DAT. Hostile penetration routes data.

Line 1: Integer number of different penetration routes.

Line 2:
- Field 1: Route number (integer)
- Field 2: Number of turnpoints in the route (include the starting point as the end point if appropriate)

Lines 3 to (number of turnpoints + 2):
- Field 1: Route number (integer)
- Field 2: Turnpoint X grid coordinate
- Field 3: Turnpoint Y grid coordinate

(Repeat format for lines 2 and 3 for all routes)

SCENARIO.DAT. This file controls the execution of the simulation model with regard to experimental design. Each of the five fields contains either a one or a zero to

indicate the level of that factor during a particular run of the experiment. These settings are output along with the simulation run results in the file OUTPUT.DAT for help in future analysis. This file only contains one line with the following five fields:

Field 1: AWACS availability.
- 0 -- not available
- 1 -- available

Field 2: Ground system configuration.
- 0 -- 407L equipment
- 1 -- MCE equipment

Field 3: Number of controllers per radar location.
- 0 -- One controller
- 1 -- Two controllers

Field 4: Attack Scenario.
- 0 -- Uniform attack distribution
- 1 -- Attack weighted toward one area (Route 8)

Field 5: Interceptor type.
- 0 -- C-min interceptor
- 1 -- C-max interceptor

<u>OUTPUT.DAT.</u> This file is written by the FORTRAN subroutine, OTPUT, and contains the output for each replication of the scenario run. The file contains as many lines as the number of replications run for the particular combination of factor settings specified in SCENARIO.DAT. In fact, the first five fields of each line is an output of the factor settings for that run in the same order specified in SCENARIO.DAT. Fields 6 - 11 are formatted as follows:

Field 6. Average number of simultaneous intercepts occurring at any point during the simulation.

Field 7. Maximum number of simultaneous intercepts occurring during the simulation. Depending

on the type of interceptor being used. this number is either C-max or C-min for that simulation run.

Field 8: Standard deviation of the number of simultaneous intercepts occurring during the simulation run. (This number, as well as the numbers in Fields 6 and 7 are based upon the number of SLAM entities in Queue number 5 which contained all interceptors that were currently 'paired' against a hostile aircraft.)

Field 9: The total number of hostile aircraft created during the simulation run.

Field 10: The number of hostile aircraft 'killed' during the simulation.

Field 11: The number of hostile aircraft 'paired' against during the simulation.

SLAM Entity Attributes

SLAM entities were created for each hostile and interceptor aircraft. The attributes for these entities are summarized in Tables E-1 and E-2.

Table E-1. Hostile Aircraft Attributes

ATRIB	Description
1	Creation Time
2	Type (20 + integer hostile type as specified in HOSSPECS.DAT
3	Speed (knots)
4	Altitude (feet)
5	X grid coordinate (Latest update
6	Y grid coordinate (Latest update
7	Penetration route number
8	Time of last event processed
9	Flight size
10	Time of next turnpoint
11	Track number
12	Time until next event
13	Status indicator 1 = flying route 2 = paired against 3 = exiting simulation
14	Exit time (finished flying route
15	Next turnpoint number
16	Heading (direction of flight

Table E-2. Interceptor Aircraft Attributes

ATRIB	Description
1	Creation Time
2	Type (10 + integer interceptor type as specified in AI.DAT
3	Speed (knots)
4	Altitude (feet)
5	X grid coordinate (Latest update)
6	Y grid coordinate (Latest update)
7	Heading (direction of flight)
8	Time of last event processed
9	Number of radar missiles
10	Number of IR missiles
11	Target track number (track number of hostile aircraft currently paired against
12	Time until next event
13	Interceptor CAP location assigned
14	Pairing indicator 0 - Not paired 1 - Currently paired
15	Weapons Controller working intercept
16	Interceptor track number

Changing the Scenario

If the user wishes to use the scenario described in Chapter 4, no changes to the actual SLAM/FORTRAN executable code are required. There are certain changes that need to be made if another scenario is desired. The first factor that needs to be checked is the initialization of the resources that indicate the number of interceptors a certain weapons controller can simultaneously control. These resources are initialized in the resource block of the SLAM network code contained in the file WI.DAT. If, for example, controller #1 at FAC #1 were capable of controlling [illegible] simultaneous intercepts, resource [illegible] would be initialized with [illegible] [illegible] controller #[illegible] [illegible] were capable [illegible]

intercepts, resource P32 would be initialized with 4 units of resource.

Although the number of CAP points; penetration routes; number, location, and types of radars; types of interceptor and hostile aircraft; and the scenario factor settings can be changed by merely changing the input data files, if other target allocation rules are needed, the FORTRAN subroutine ALLOC must be changed. As ALLOC is currently written, each of the six radars in the scenario are given responsibility for control of certain CAP locations against a particular penetration route. Secondary and tertiary responsibilities are also prescribed. With each theater modeled, these responsibilities may change with the daily tasking. The user should decide upon a set of responsibilities to be modeled and re-write ALLOC to model the system being studied.

As currently implemented, ALLOC is a set of IF-THEN rules that match the proper controller with an available interceptor against a particular penetrating hostile aircraft. The local variable, "LOOP", is used to avoid getting caught in an infinite loop while searching to make an allocation against a particular hostile aircraft. [illegible] allocation can be made against the most threatening [illegible] aircraft, ALLOC continues the search until either an allocation can be made against [illegible] hostile aircraft or determines that [illegible] made at that time.

Appendix F. Weapons Controller Task Analysis

Before the prototype simulation model was developed, several possible approaches were considered. One of the approaches was to try to model the weapons controller as an individual and try to determine at what point the controller became task saturated and could not control another interceptor. The controller would then not be allowed to control another interceptor until the task loading decreased enough to allow the extra workload required to control that next interceptor.

Before finally deciding that this approach would require much more detail than necessary in a theater level simulation, a brief task analysis of the weapons controller job was performed. This task analysis was based upon the author's experience as a weapons controller and is presented below. Each task is described with respect to the time required for completion of the task, its priority, how often the task is repeated, and if the completion of the task can be either ignored or somehow compressed.

This analysis is presented for the reader's [illegible] only and should not be considered a complete [illegible] description of the tasks associated with the weapons controller duties.

[illegible]

PRIORITY: Essential if CLOSE or TACTICAL control is to be given...also essential for THREAT WARNING or EMERGENCIES.

RECURRENCE: Each time a new interceptor "checks in" or tracking (either computer or personal) is lost.

IGNORE/COMPRESS: Can be ignored if BROADCAST control is all that is expected. Cannot usually be compressed...either the controller knows where UNKNOWN and additional measures to ID must be undertaken (intercept, VIS ID, etc) The initial ID process is usually done by the surveillance section, but the weapons controller may assist.

TASK: ID HOSTILE/POTENTIALLY HOSTILE A/C

TIME REQUIRED: Up to 2 minutes allowed by regulation. If track is not identified within 2 minutes, it is considered UNKNOWN and additional measures to ID must be accomplished (i.e. visual ID, etc.). This task is normally accomplished by the surveillance section of the radar unit, but the weapons controller may be tasked to assist in the ID function.

PRIORITY: ESSENTIAL

RECURRENCE: Each time a new unknown track appears or tracking is lost on a previously known hostile.

IGNORE/COMPRESS: None.

TASK: TRACK FRIENDLY A/C

TIME REQUIRED: 0 to 45 seconds...0 if computer is tracking and all appears well...10 to 15 seconds per track (normally) without making a mistake entering data in computer...up to 45 seconds (or more) if fumble fingered.

PRIORITY: Moderately essential for good CLOSE or TACTICAL control...if tracking is off by a small degree, the controller can adjust the information provided by the computer by "eyeball."

RECURRENCE: Every sweep (update) of the radar picture. No action may be required if the computer tracking is adequate.

IGNORE/COMPRESS: May be ignored as long as situation awareness can be maintained (good computer tracking or only minor errors) ... controller may be able to update computer in ... seconds per track.

TASK:	TRACK HOSTILE A/C
TIME REQUIRED:	Same a tracking friendly A/C
PRIORITY:	Essential for air defense. Only task that takes priority is helping an emergency. Even during an emergency, this is essential for threat warning.
RECURRENCE:	Same as tracking friendly A/C.
IGNORE/COMPRESS:	An efficient controller can minimize the time to update the tracking on a hostile...less than 5 seconds per track updates on a previously defined hostile.

TASK:	PROVIDE BOGEY DOPE
TIME REQUIRED:	10-30 seconds...usually not given all at once, but broken up into several smaller radio transmissions
PRIORITY:	Secondary...cannot be accomplished unless tracking on both the hostile and friendly is maintained. Essential, however if the controller is to provide any control to the friendly interceptor.
RECURRENCE:	Every 2 minutes (unless the pilot requests more) while the friendly is still closing on the hostile...every 30 seconds when the fighter and hostile are within firing range.
IGNORE/COMPRESS:	Can be ignored if the friendly has full information on the hostile from his own weapons system. Essential warning can be compressed to 5 seconds.

TASK:	KEEP COMPUTER UPDATED
TIME REQUIRED:	10 seconds - minutes...depends if a new track is being entered, track symbology is being moved, computer pairing is being accomplished, etc.
PRIORITY:	Tertiary to tracking and providing bogey dope... control can be accomplished without computer assistance, but the computer can help determine intercept vectors and help keep situation awareness through auto tracking.
RECURRENCE:	As determined necessary by the controller.
IGNORE/COMPRESS:	Can be ignored if manual control is provided.

TASK:	COMPUTE INTERCEPT/HEADING VECTORS
TIME REQUIRED:	5 - 45 seconds
PRIORITY:	Only necessary for close control or emergencies
RECURRENCE:	During close control, once at the beginning of the intercept and then as needed for corrections.
IGNORE/COMPRESS:	Not needed for TACTICAL/BROADCAST control. Can be compressed into a "snap vector" (i.e. best guess heading to get going in the right direction.)

TASK:	UPDATE FRIENDLY STATUS
TIME REQUIRED:	30 seconds - several minutes
PRIORITY:	Low...only accomplished when all other tasks are accomplished
RECURRENCE:	0 - 2 times per mission
IGNORE/COMPRESS:	Usually ignored...proper communications brevity can compress this to less than a minute

TASK:	PROVIDE THREAT WARNING
TIME REQUIRED:	5 - 10 seconds
PRIORITY:	Very high...could keep a friendly from getting killed.
RECURRENCE:	Every time a hostile gets within 5 - 10 miles from a friendly without previous warning.
IGNORE/COMPRESS:	N/A

TASK:	MONITOR ENEMY MOVEMENTS
TIME REQUIRED:	0 - 5 seconds
PRIORITY:	Essential for enemy tracking...Also needed for intercept corrections.
RECURRENCE:	Every radar update as necessary.
IGNORE/COMPRESS:	Can be ignored if computer tracking is being used and appears to be good.

TASK:	UPDATE COMPUTER TRACKING
TIME REQUIRED:	5 - 20 seconds
PRIORITY:	Low
RECURRENCE:	Whenever computer tracking gets off of the radar data and auto tracking doesn't restore it.
IGNORE/COMPRESS:	Can be ignored as long as auto tracking is working or the symbology is not off enough to detract from situation awareness.

TASK:	PROVIDE "SITUATION BRIEFINGS"
TIME REQUIRED:	30 seconds to 2 minutes
PRIORITY:	Low...only needed after tracking is established and intercepts are not being pursued currently
RECURRENCE:	Once for each flight as it comes "on station" and every several minutes thereafter if nothing else is happening
IGNORE/COMPRESS:	Ignore if busy with intercepts ...compress with special prebriefed procedures (bullseye points, grid system, etc).

TASK:	PUT COMPUTER SYMBOLOGY ON RADAR DATA
TIME REQUIRED:	5 -45 seconds
PRIORITY:	Necessary for computer tracking and for data links.
RECURRENCE:	Once for each track unless symbology accidentally destroyed.
IGNORE/COMPRESS:	Can be compressed by creating several of the same type of symbologies rather than "tagging" one type of data then another.

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VITA

Captain Donald W. Clements was born on 11 February 1954 in Richmond, Virginia. He graduated from high school in Gloucester, Virginia in 1972. He attended the United States Air Force Academy and received a Bachelor of Science degree in Basic Sciences and his commission in June 1976. After an unsucessful attempt in Undergraduate Pilot Training, he completed training as an Air Weapons Controller in August 1977. As a weapons controller, Capt Clements served in ground radar units at Eglin AFB, Florida and Osan AB, Republic of Korea. He then became qualified as an AWACS weapons controller and served in the 964 AWAC Squadron, Tinker AFB, Oklahoma and the 961 AWAC Squadron, Kadena AB, Okinawa, Japan until entering the School of Engineering, Air Force Institute of Technology, in August 1985. While at the 961st, Capt Clements was responsible for scheduling the AWACS effort in response to the Soviet shootdown of KAL Flight 007, and later was Chief of AWACS Plans for the Pacific region.

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